Star Formation in relation to Future X-ray Missions:

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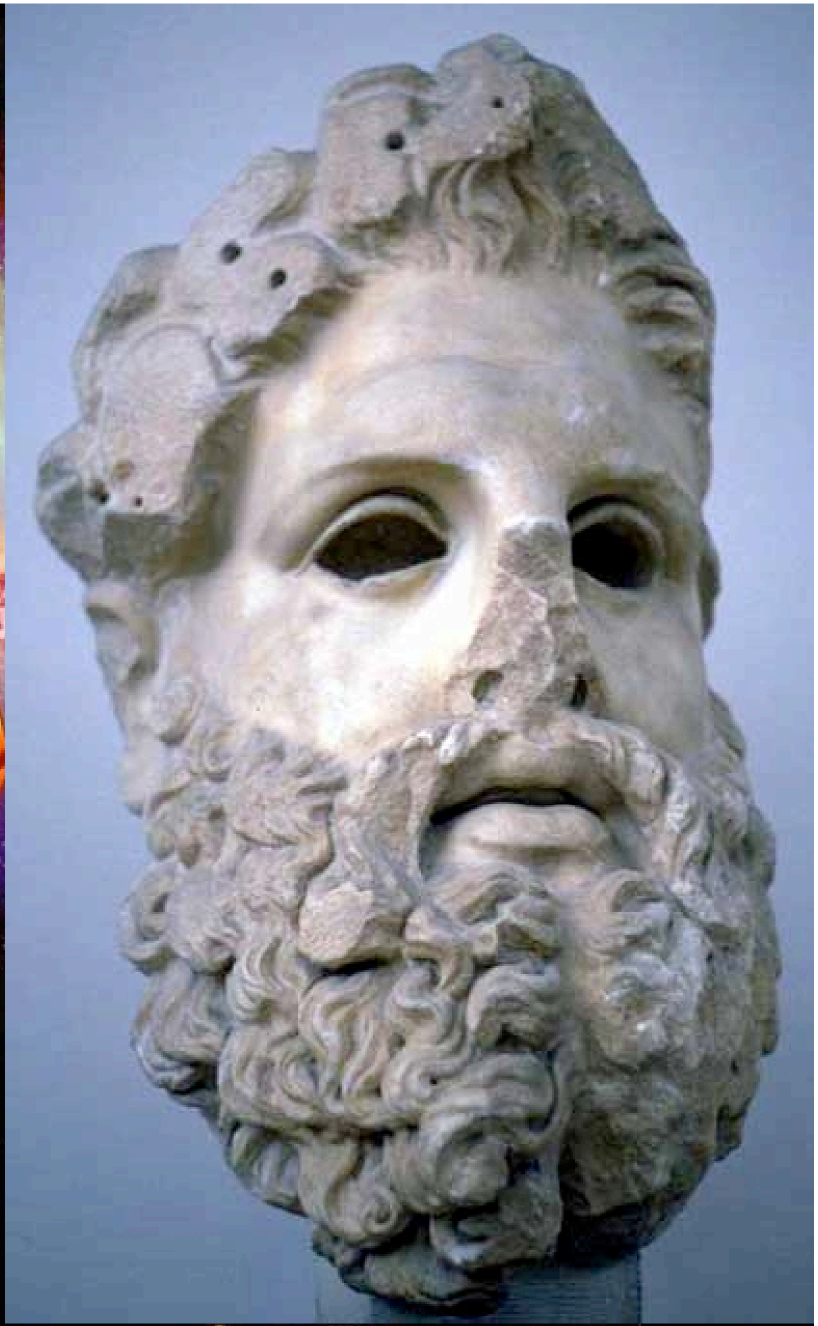


Science Drivers

- Star formation from the X-ray perspective: eg. the IMF, binary fraction and metalicity vs. redshift
- Feedback: supernovae metal enrichment and energy injection via heating
- Environmental effects: interaction and mergers, gaseous effects such as HI confinement of X-ray winds
- Understanding the AGN/star formation connections at epochs of max.starformation and quasar activity Good news, maybe at lower z than thought previously!

Talk Outline

- Studies of SF components in the local universe, as templates for understanding more distant of objects
- Prospects for studies of starformation at medium and high redshift
- General context of X-ray observations of SF galaxies in the era of ALMA/Herschel/ELT/JWST/SKA etc.

Hard X-rays vs. radio cont. and far infrared

Really need to understand calibration from low to high SFR

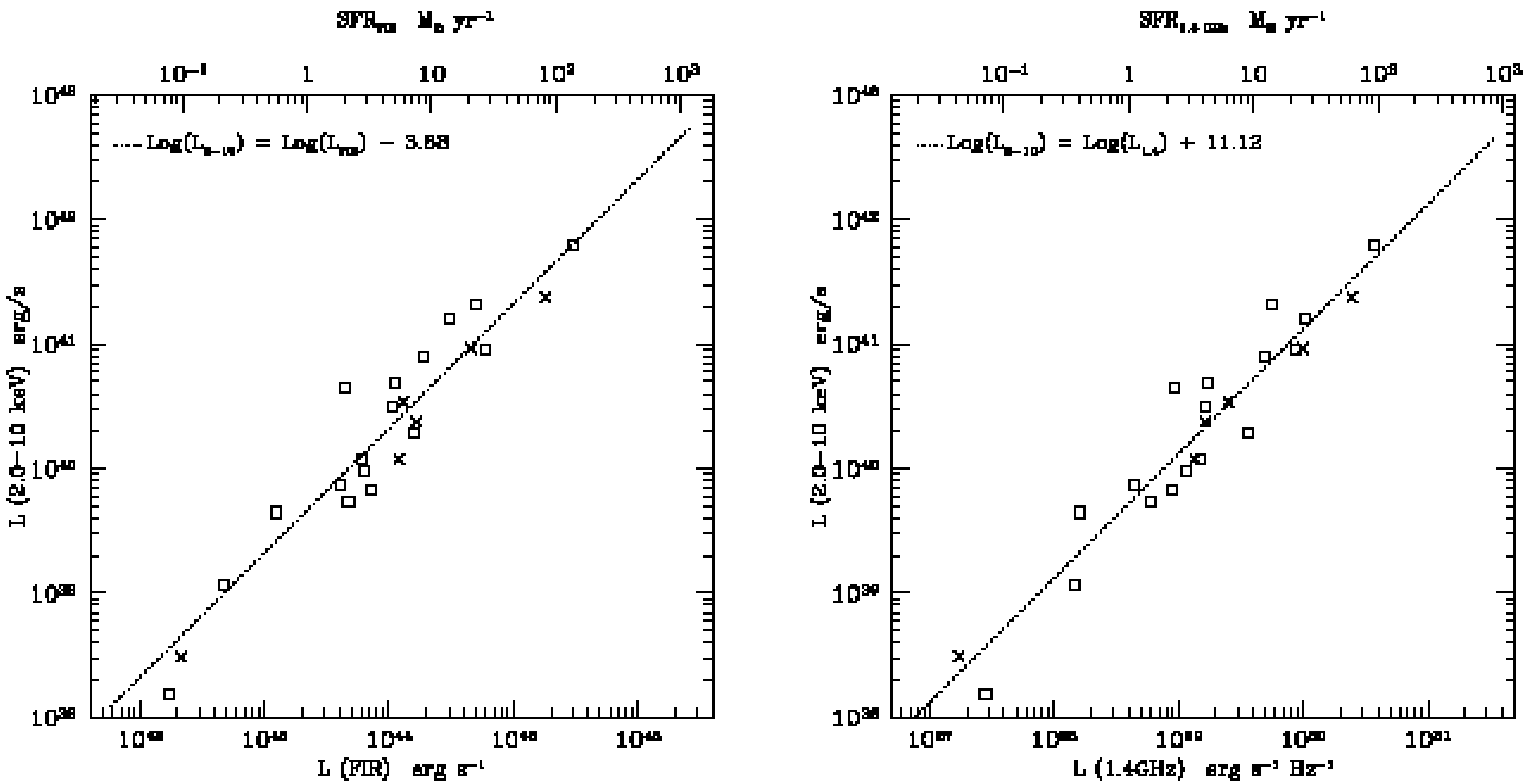
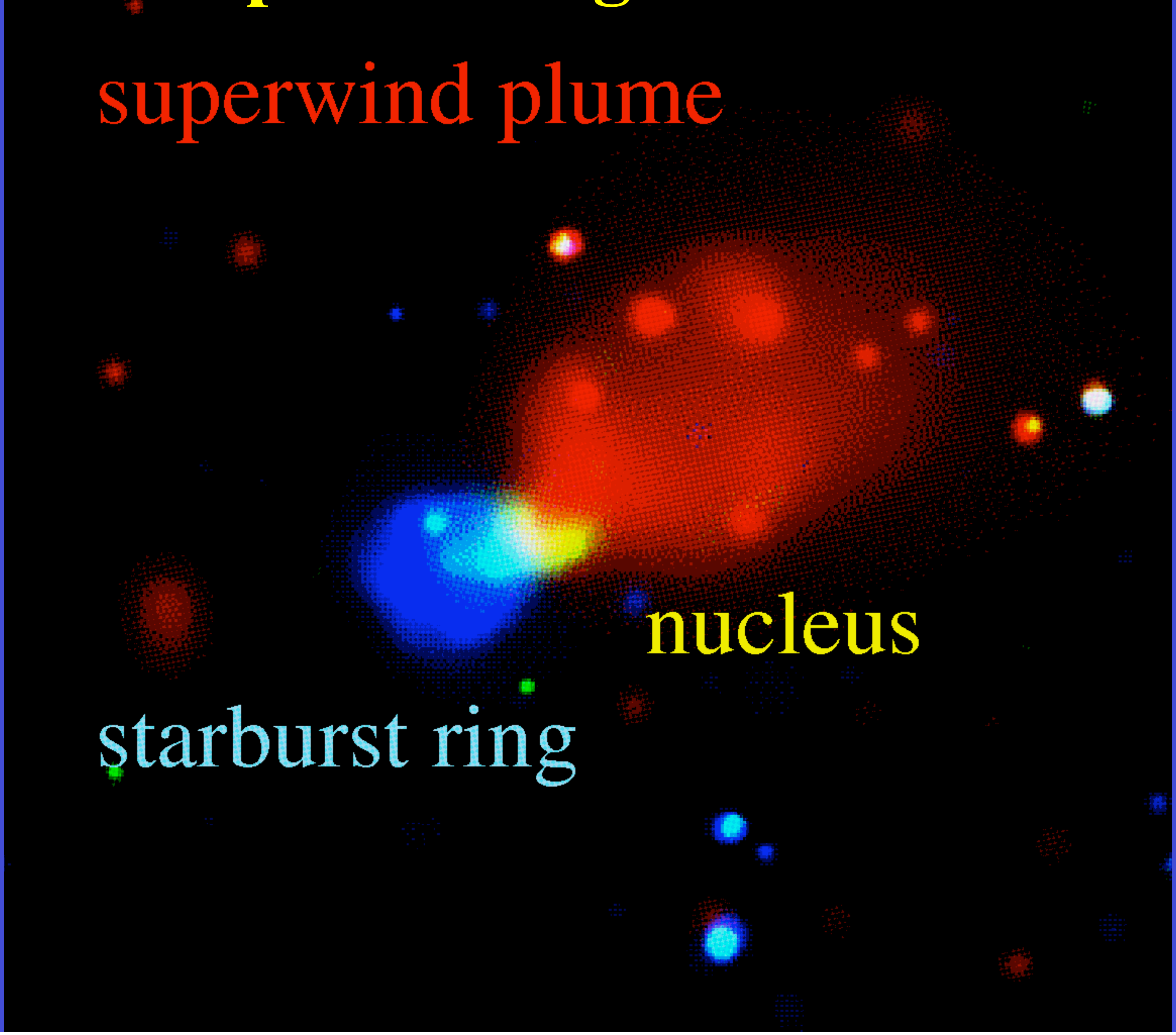
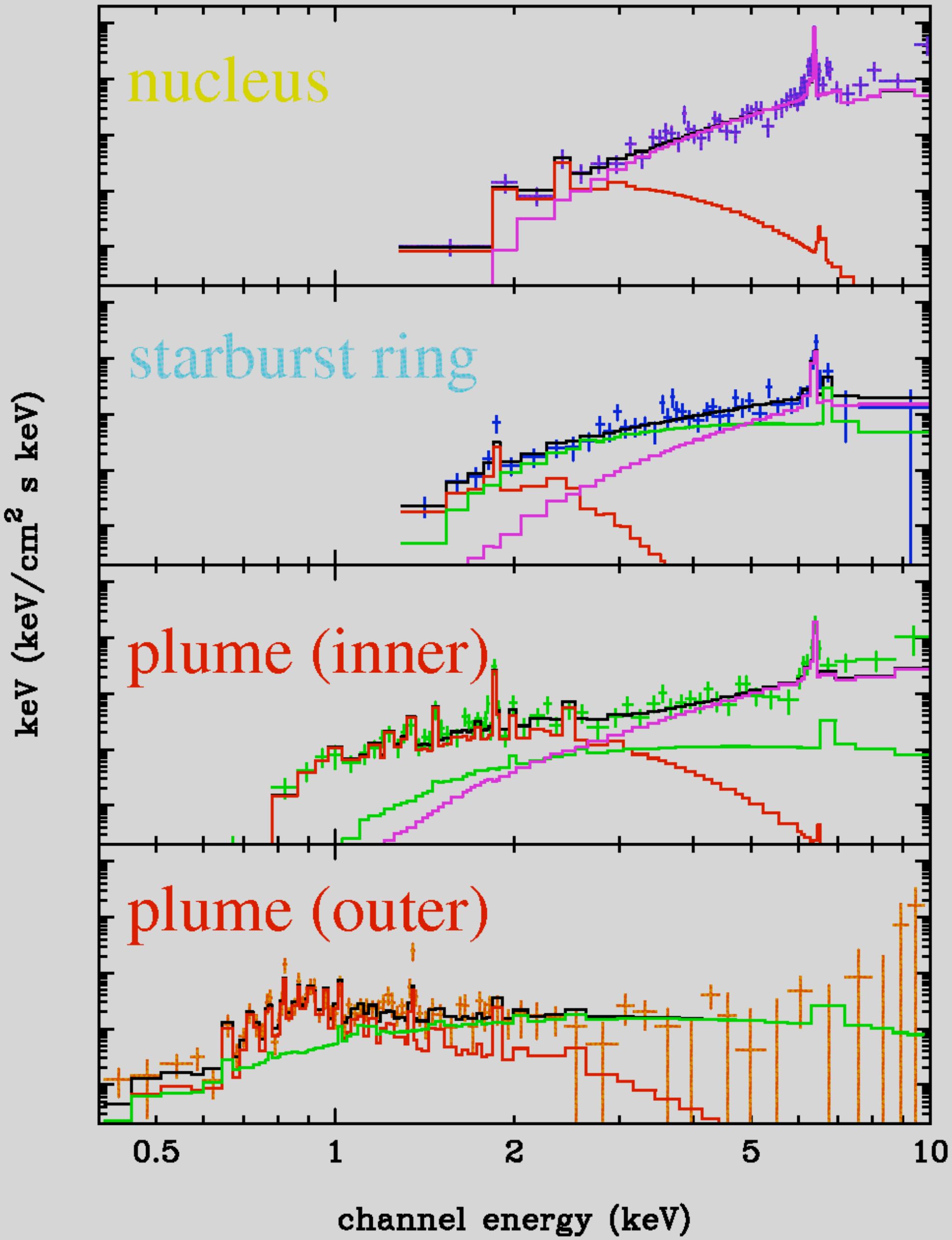


Fig. 2. The 2.0–10 keV luminosity of local star-forming galaxies vs. radio and FIR ones. Symbols as in Fig. (1); dotted lines: Eqs. (12,13).

Detailed Studies of Multiple X-ray Components eg. in NGC4945



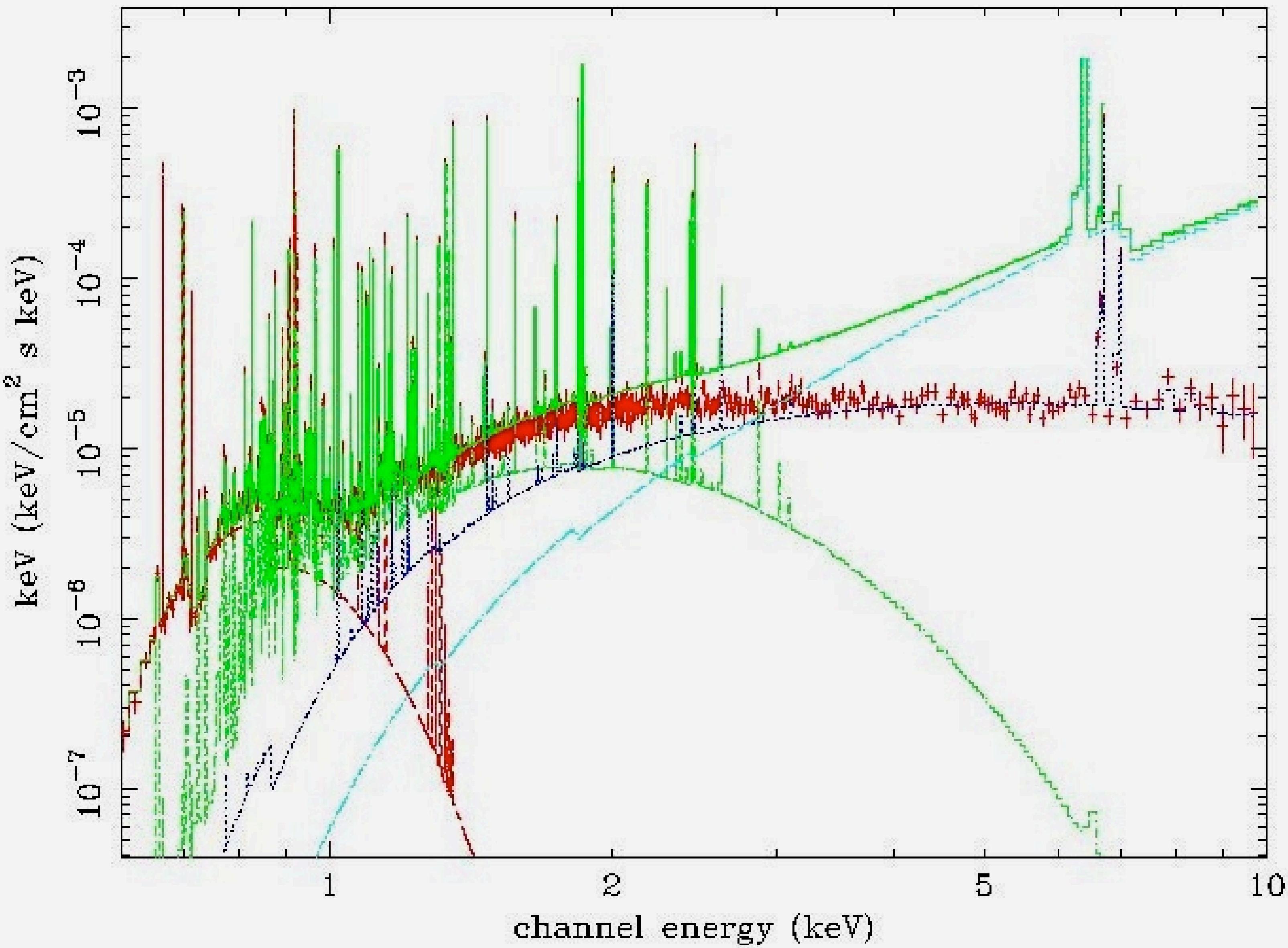
X-ray Components in NGC4945



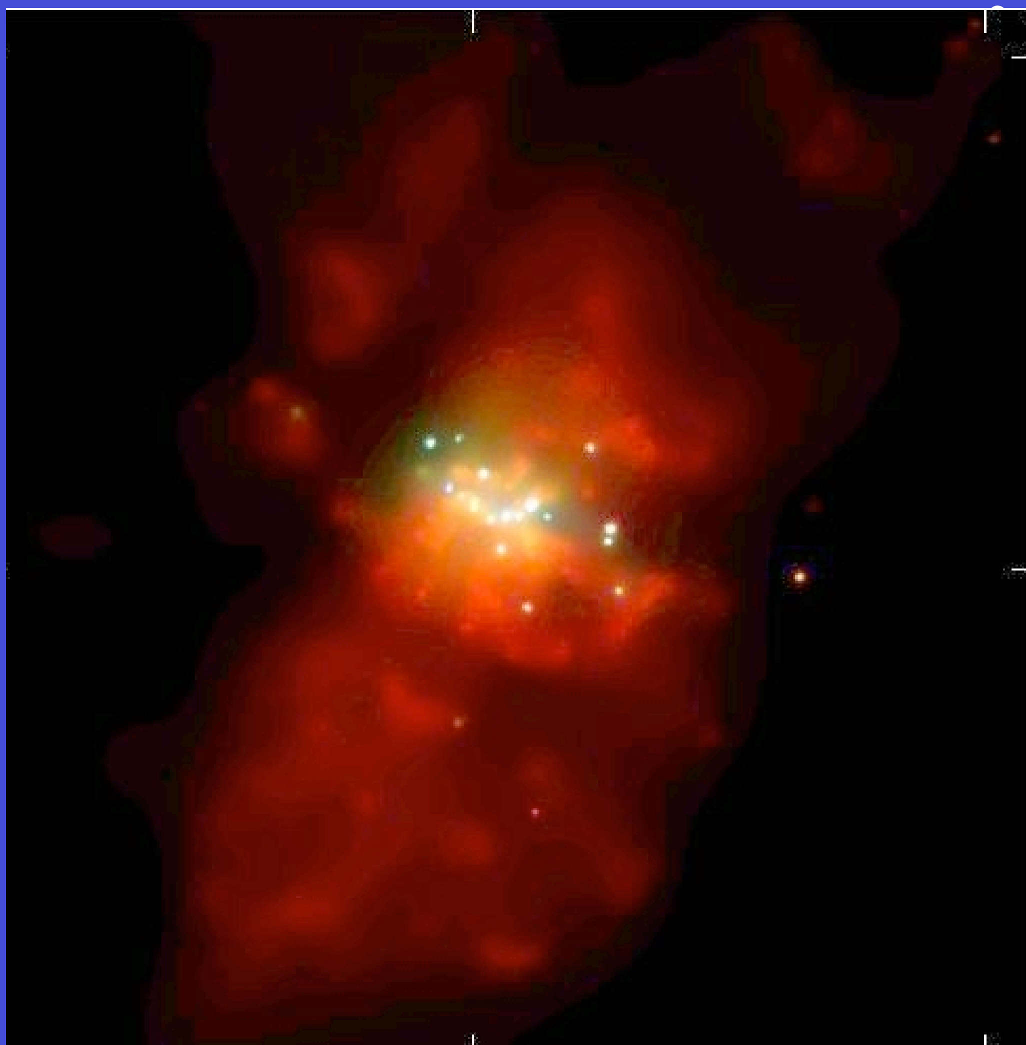
Good energy coverage needed

Good spatial resolution needed

Taking model for NGC4945 thru XEUS/STJ matrix
Lx = 1x10E38 ergs/s, at 3.7Mpc for 100ksec. (140K counts)



M82: Chandra X-ray Observations



12/24 are variable on timescales of 1-6 months

90% of soft emission. and

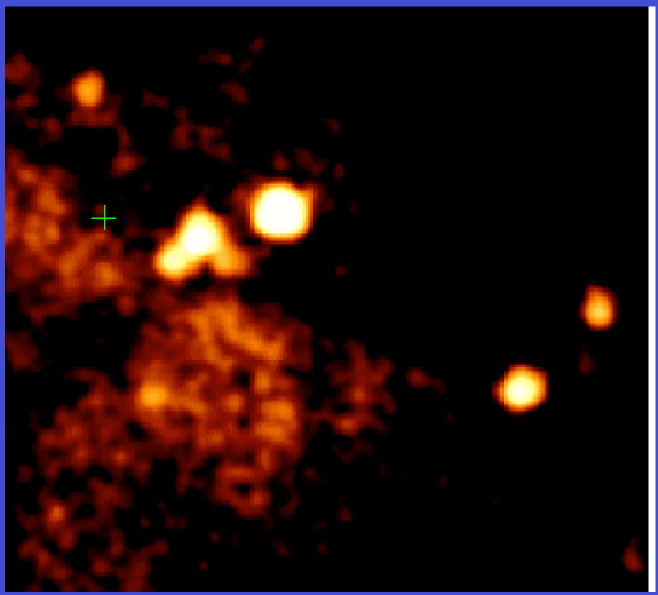
50% of hard, is diffuse

Gas velocities along cone ~600 km/s

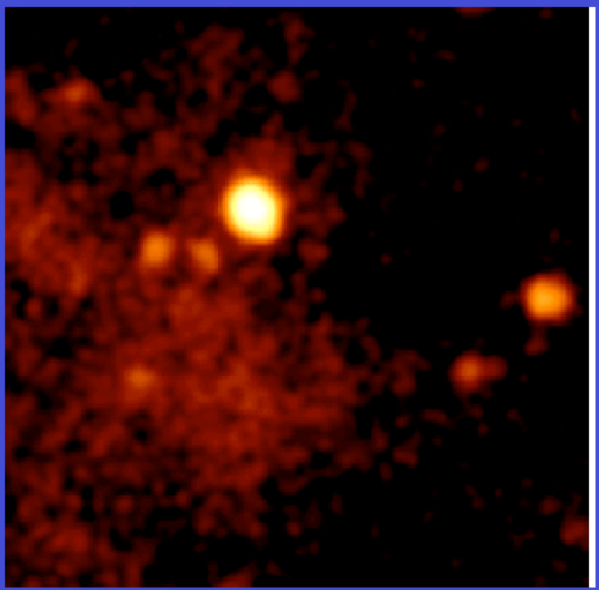
One source is highly variable and reaches

$L_x > 10^{41}$ erg/s

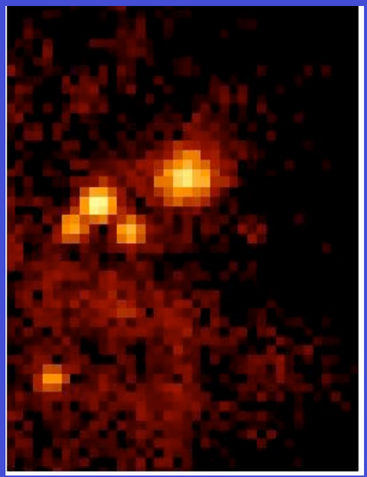
M82 : Snapshot observations



October 1999



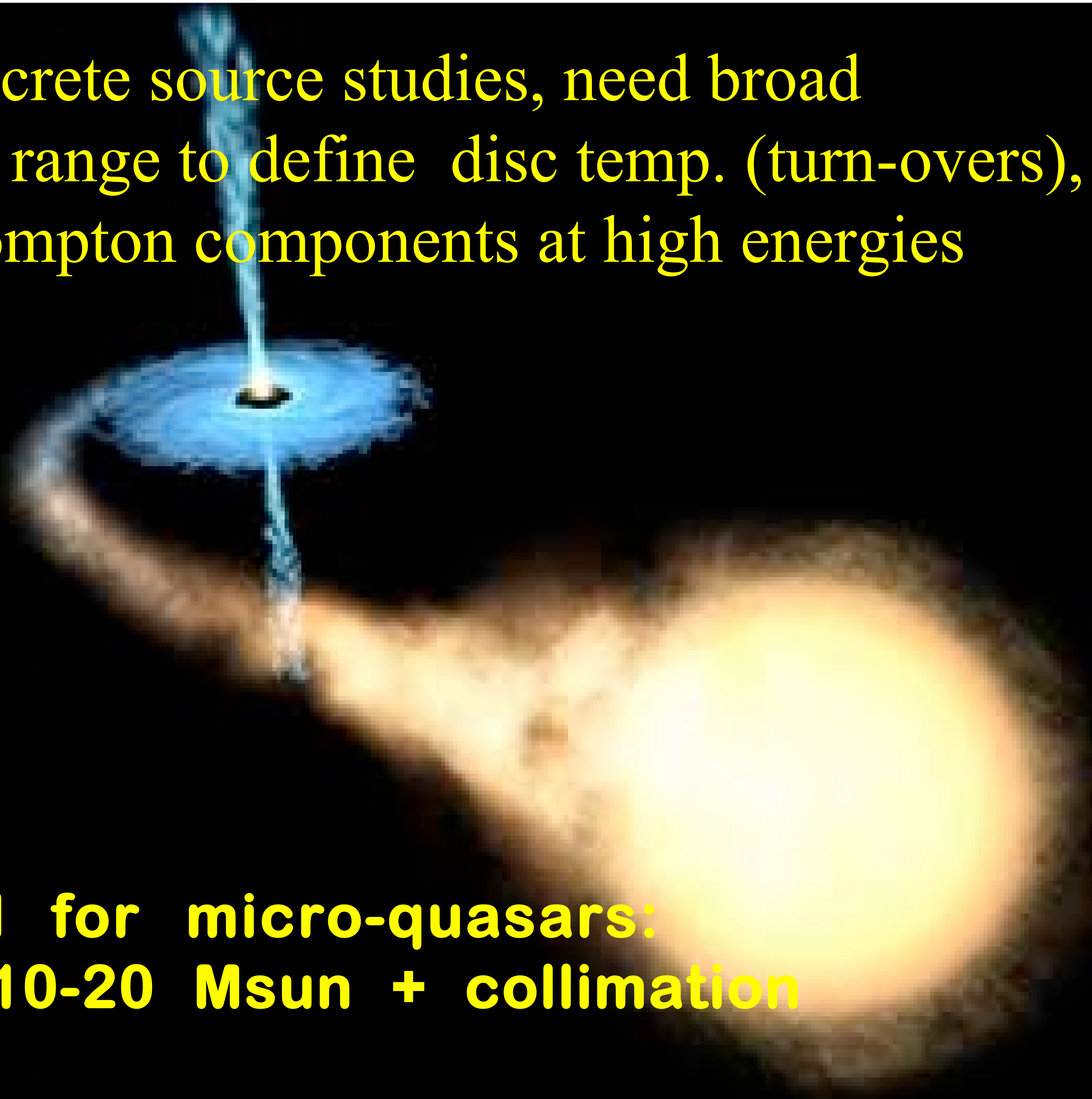
January 2000



June 2002

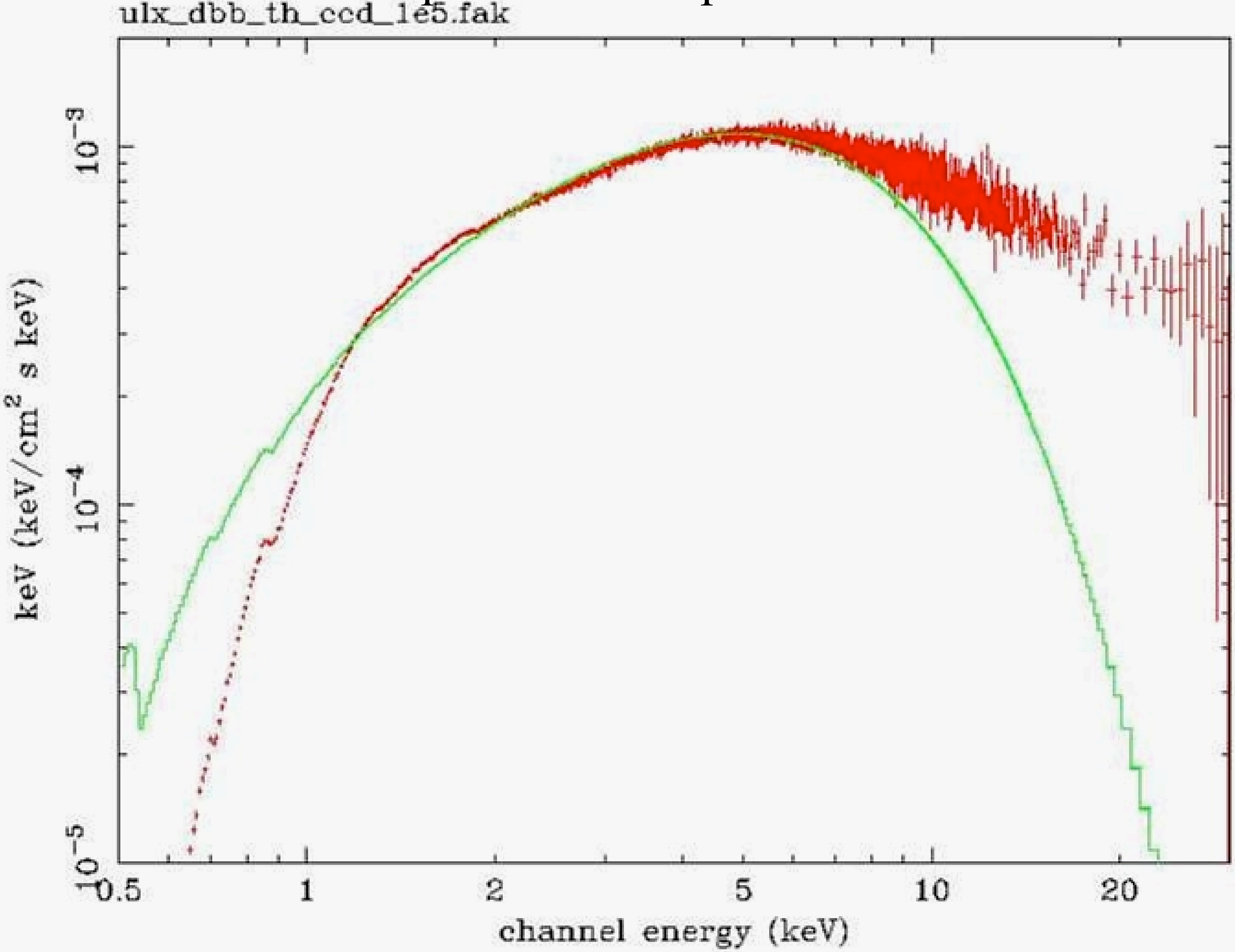
Dynamical centre of M82 shown by the green cross

For discrete source studies, need broad energy range to define disc temp. (turn-overs), and Compton components at high energies

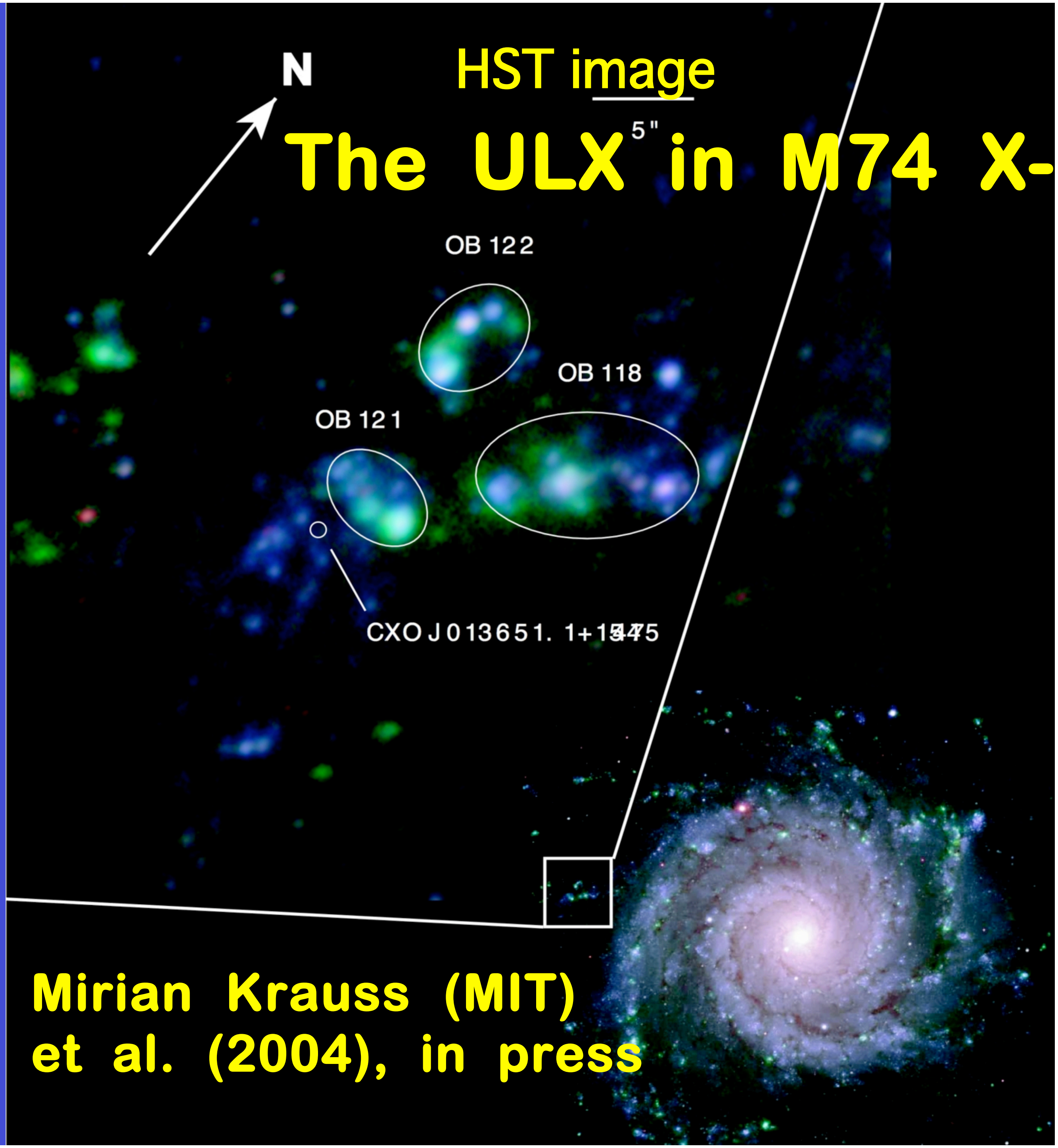


Model for micro-quasars:
BH ~10-20 Msun + collimation

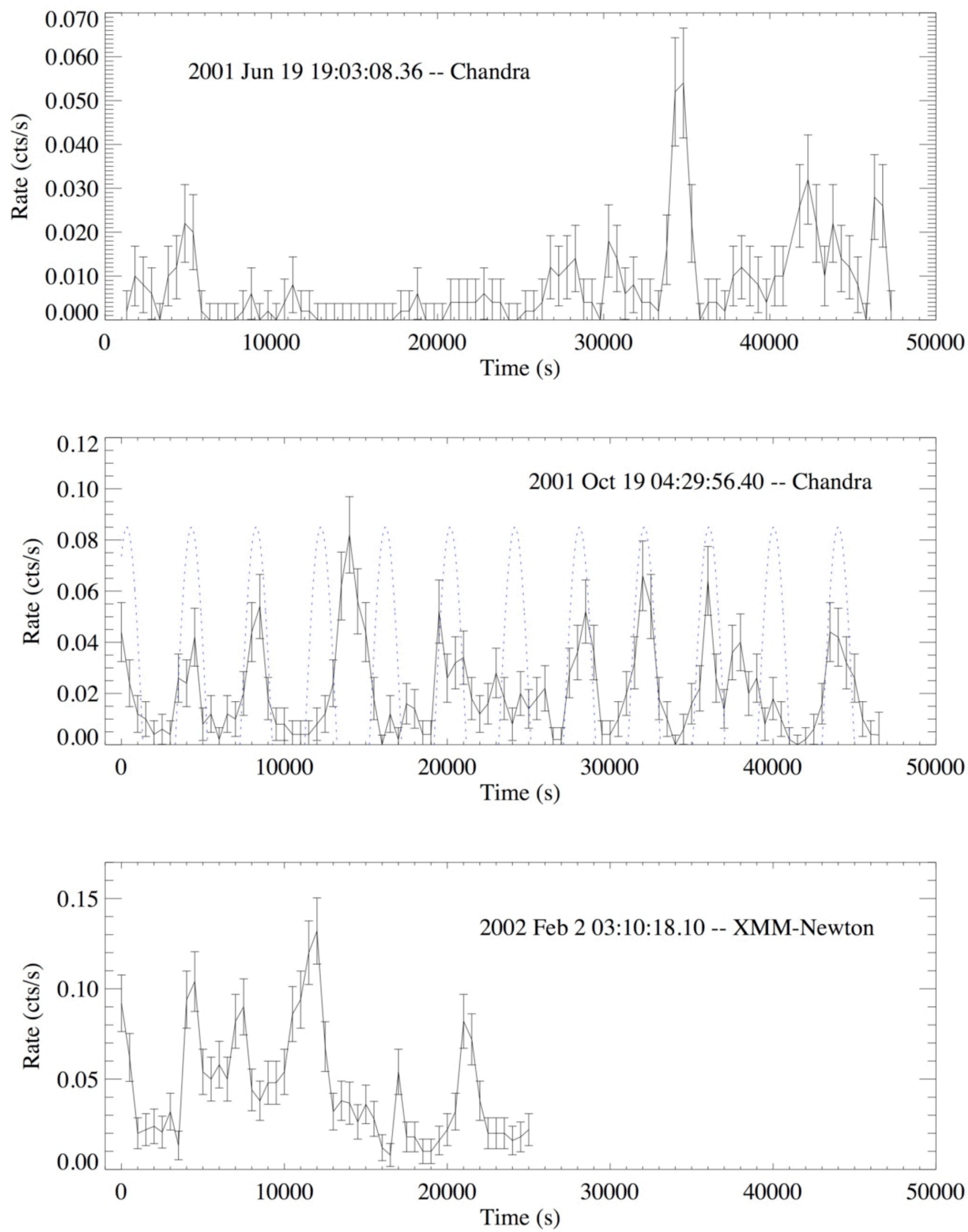
Lx =5x10E39 ergs/s, at 4Mpc 100Ksec, Green line is hot 2keV disc, Red is a disc with comptonised .component.



Timing studies: need large collecting area

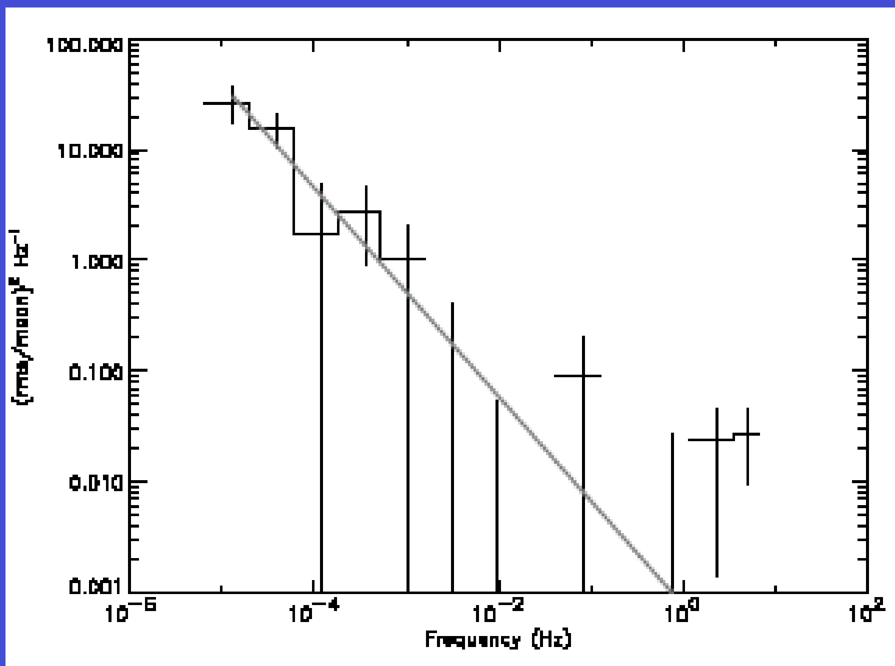


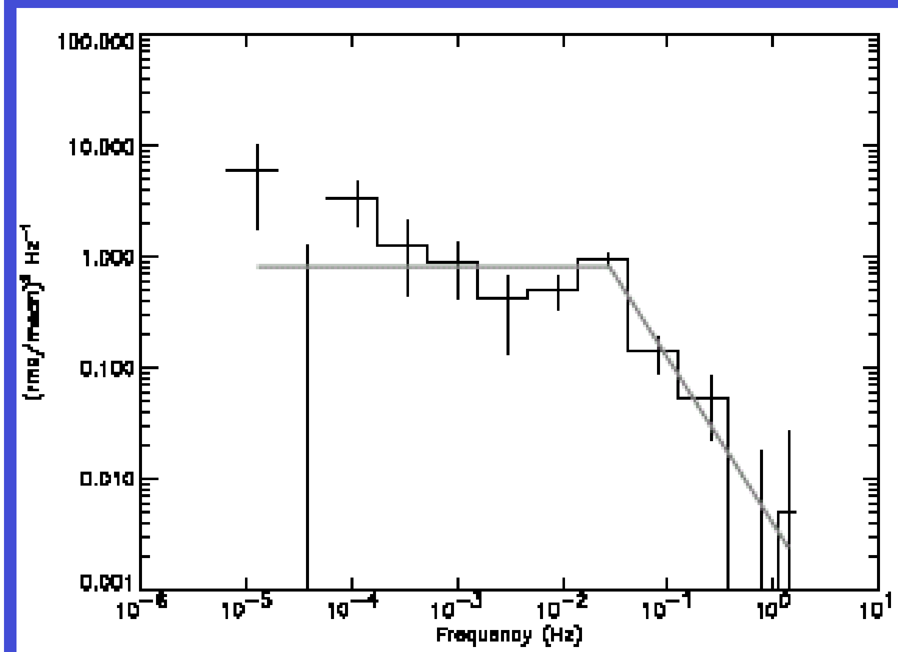
X-ray light curve of ULX M74 X-1



Power density spectra of ULXs in NGC4559

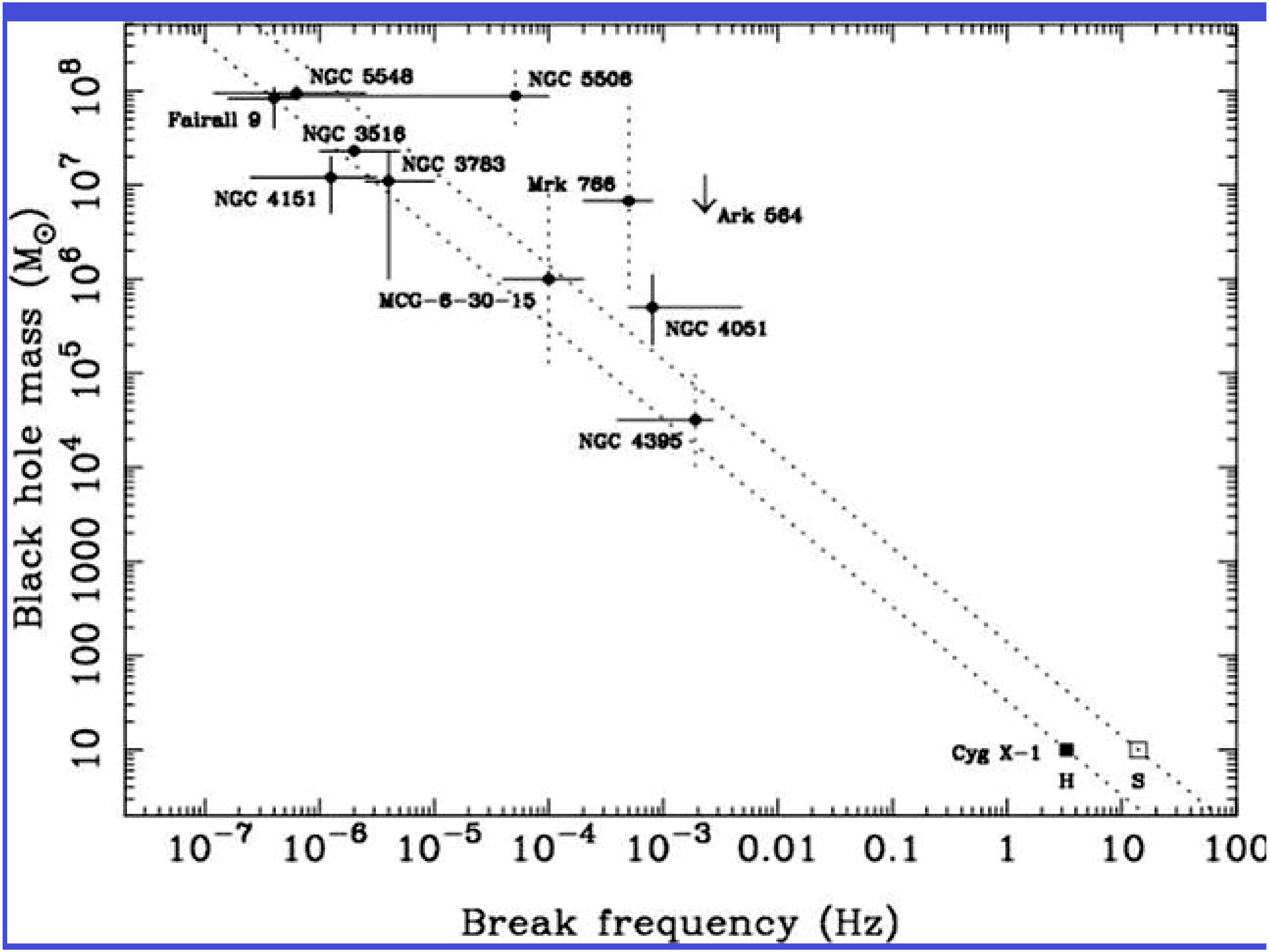
Distance = 10Mpc. Cropper et al, MNRAS (2004)





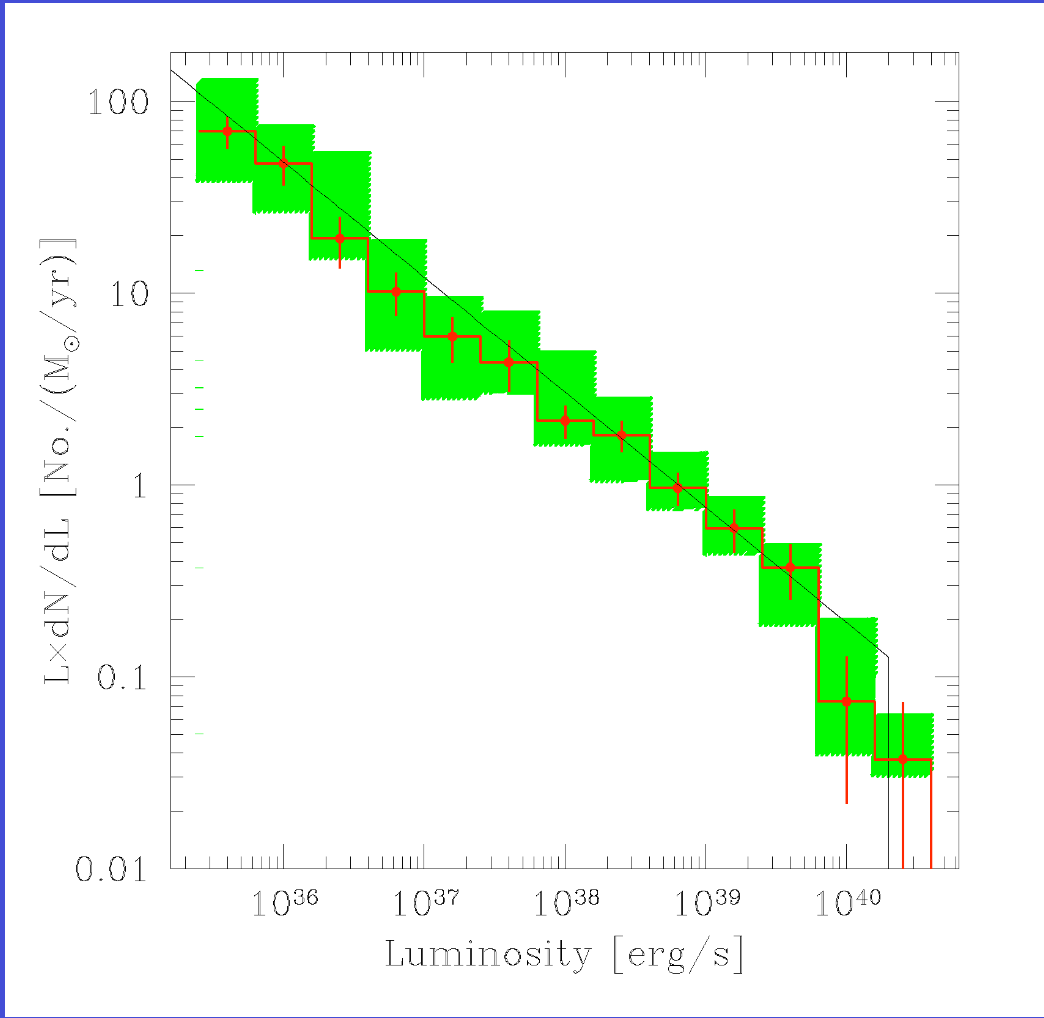
Source X-10

Source X-7, showing break at 38 mHz



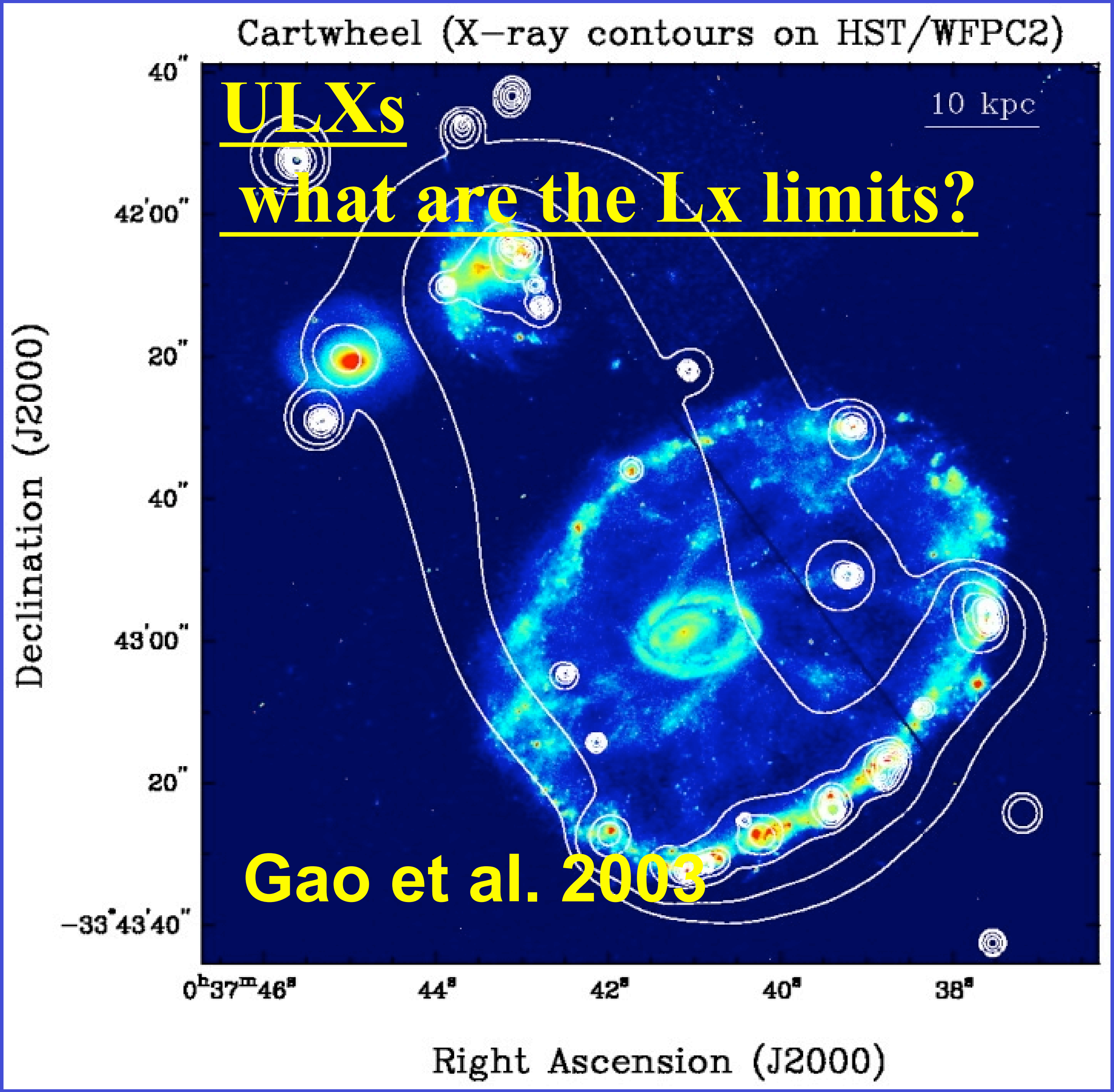
NGC 5548
NGC 5506
Fairall 9
NGC 3516
NGC 3783
NGC 4151
Mrk 766
Ark 564
MCG-6-30-15
NGC 4051
NGC 4395
Cyg X-1
H
S
Black hole mass ($M_\odot$)
Break frequency (Hz)
10^8
10^7
10^6
10^5
10^4
1000
100
10
10^{-7}
10^{-6}
10^{-5}
10^{-4}
10^{-3}
0.01
0.1
1
10
100

Combined luminosity function of HMXBs in starburst gals. The Milky Way and SMC



Grimm, Gilfanov & Sunyaev, (2003)

no break ~ 10^{39} erg s^{-1}: most ULXs are HMXBs



Cartwheel (X-ray contours on HST/WFPC2)
ULXs
what are the Lx limits?
10 kpc
Gao et al. 2003
40"
42'00"
20"
40"
43'00"
20"
−33°43'40"
Declination (J2000)
0h37m46s
44s
42s
40s
38s
Right Ascension (J2000)

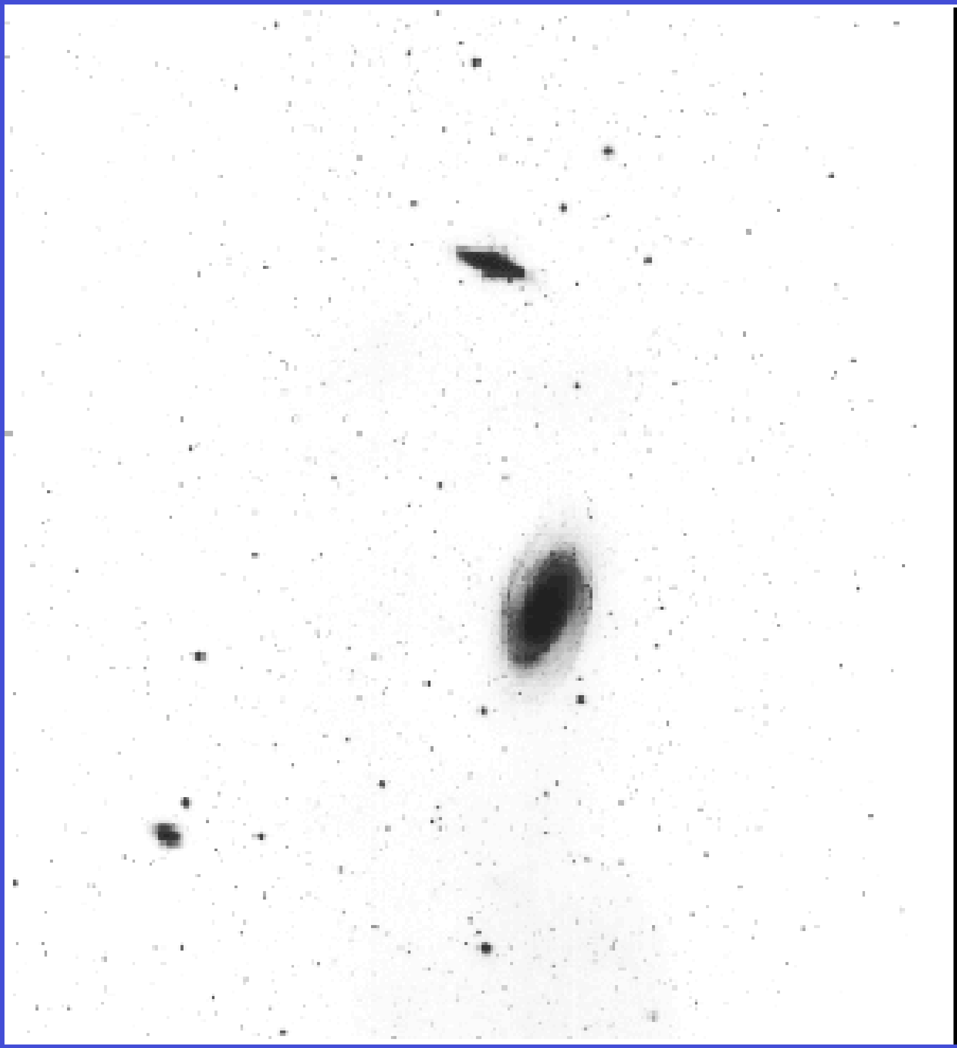
The Importance of Environment

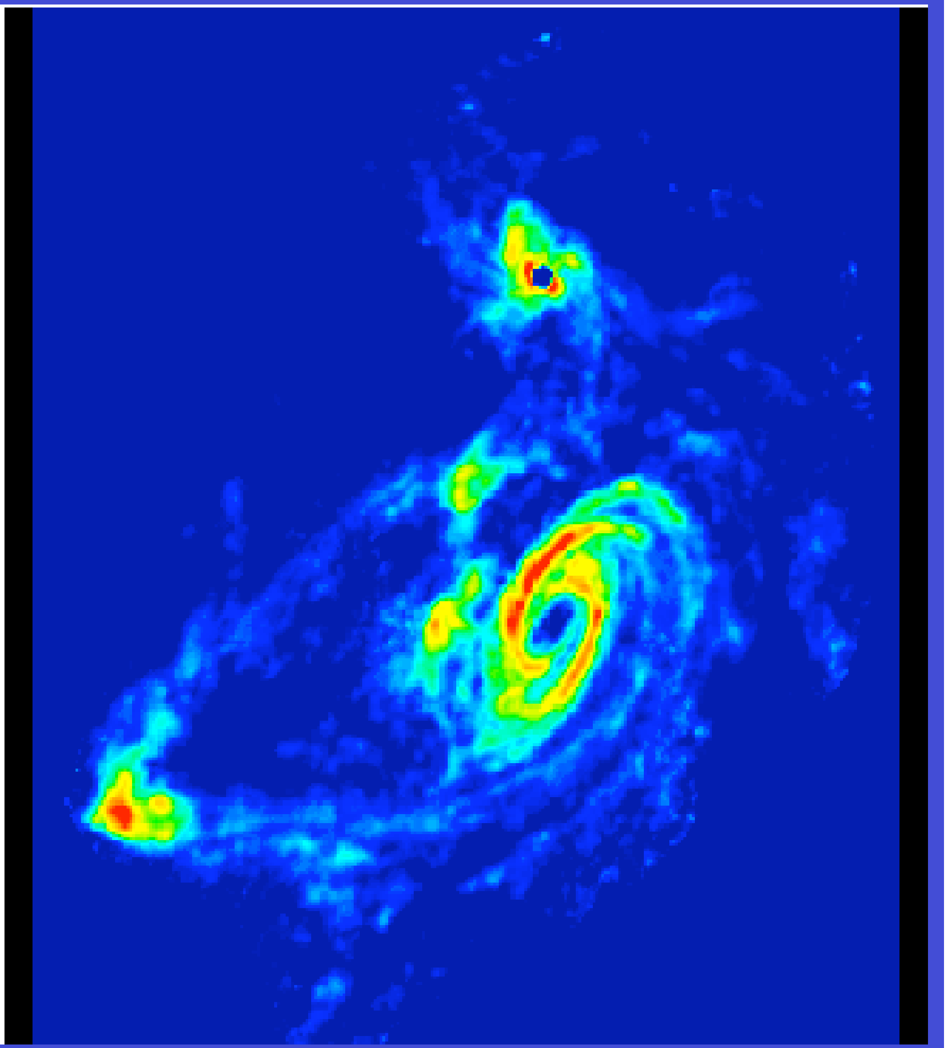
- Local galaxy population: interactions, mergers, groups, and clusters
- Gaseous environment: density, HI etc.
- Feedback into the environment from the starburst activity

The Interacting Group, M81, M82, NGC3077,

DSS optical Image

Radio, 21cm HI

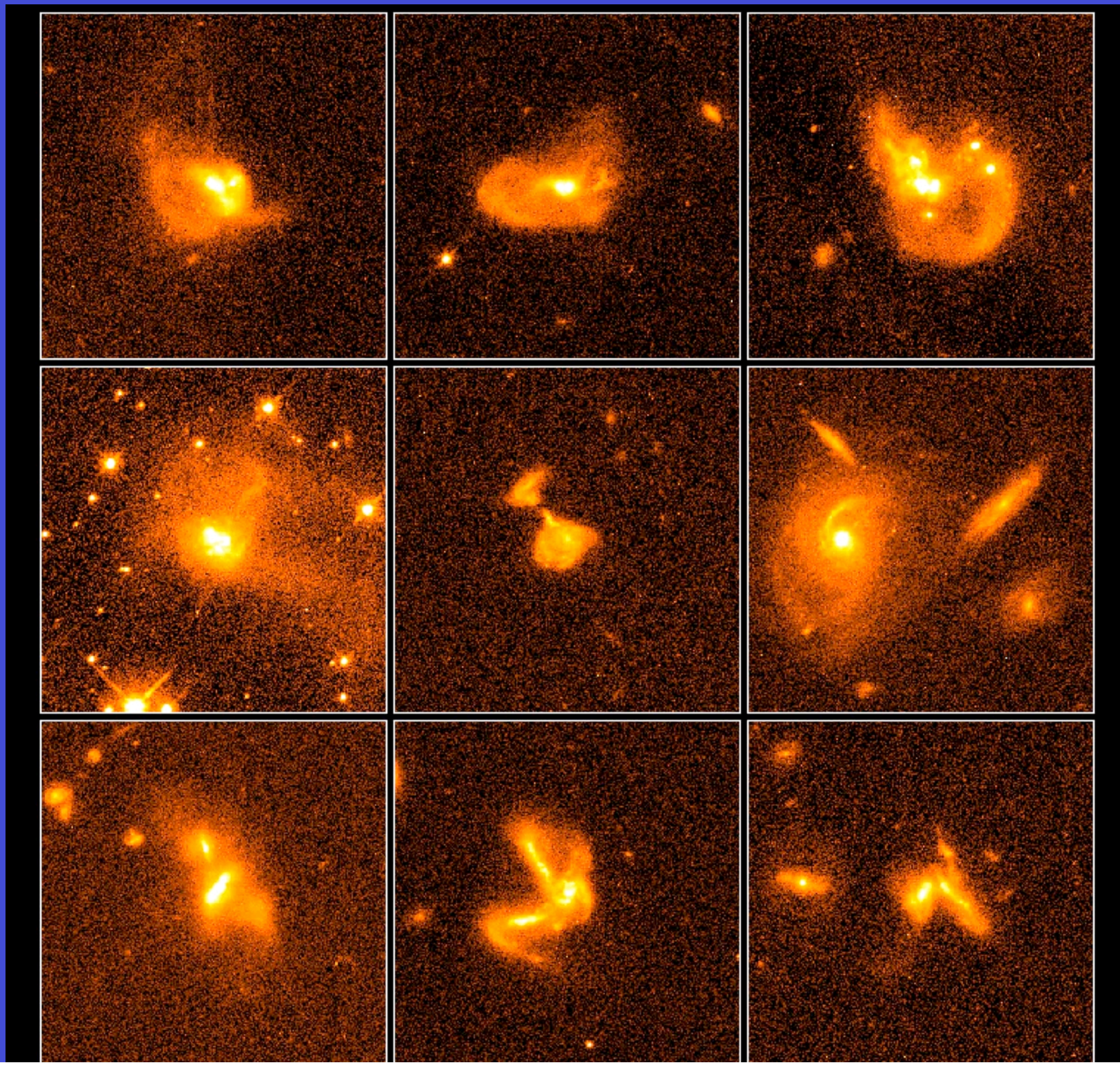




Galaxies with very high SFRs

- ULIRGs, and so-called “SCUBA” galaxies, with SFRs 100-1000’s solar masses per year
- Lyman break and Balmer break galaxies
- Q. Did most stars form in galaxies undergoing quiescent SF, or in violent bursts?

ULTRALUMINOUS INFRARED GALAXIES: L(FIR) > 10^{12} Ls



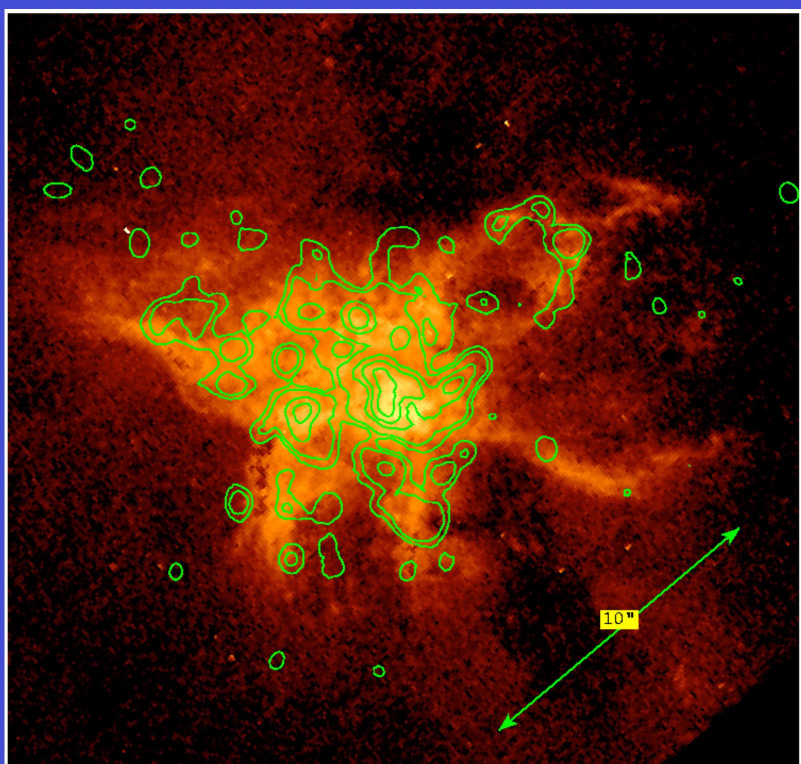
AGN/Starburst: the case of NGC6240

- Extended soft X-ray emission dominated by starburst superwind

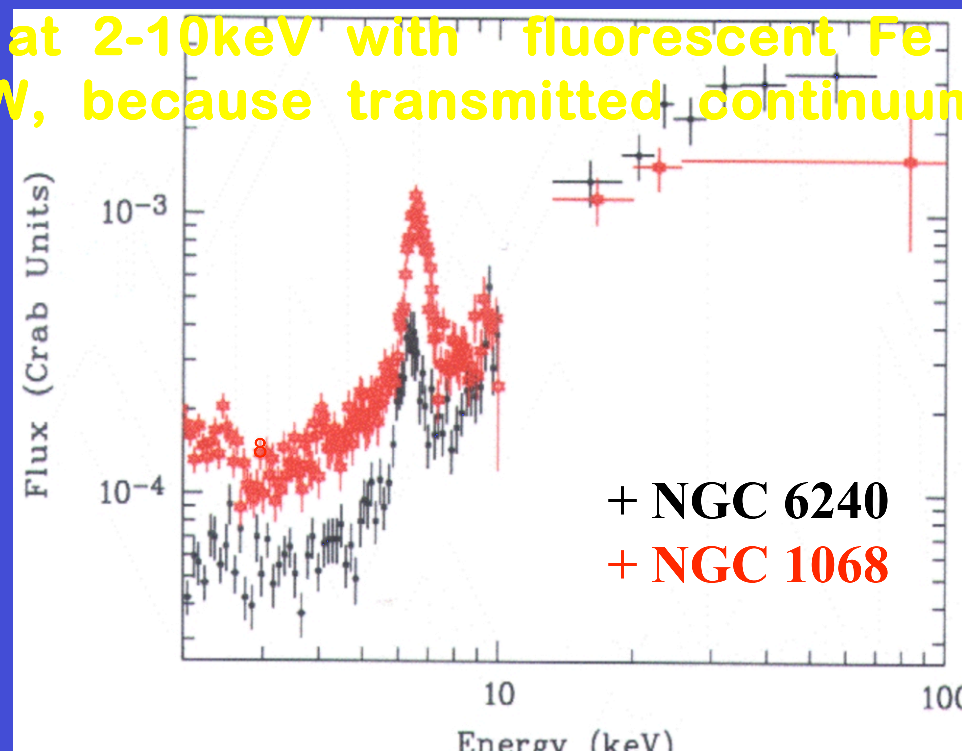
Lx ~ 10E41erg/s

- Direct transmitted AGN emission at >10keV by BeppoSax and RXTE

at 2-10keV with fluorescent Fe K
W, because transmitted continuum



Lira et al. 2002



Vignati et al. 1999

Chandra Observations of the Merger System NGC 6240 – Komossa et al. (2003)

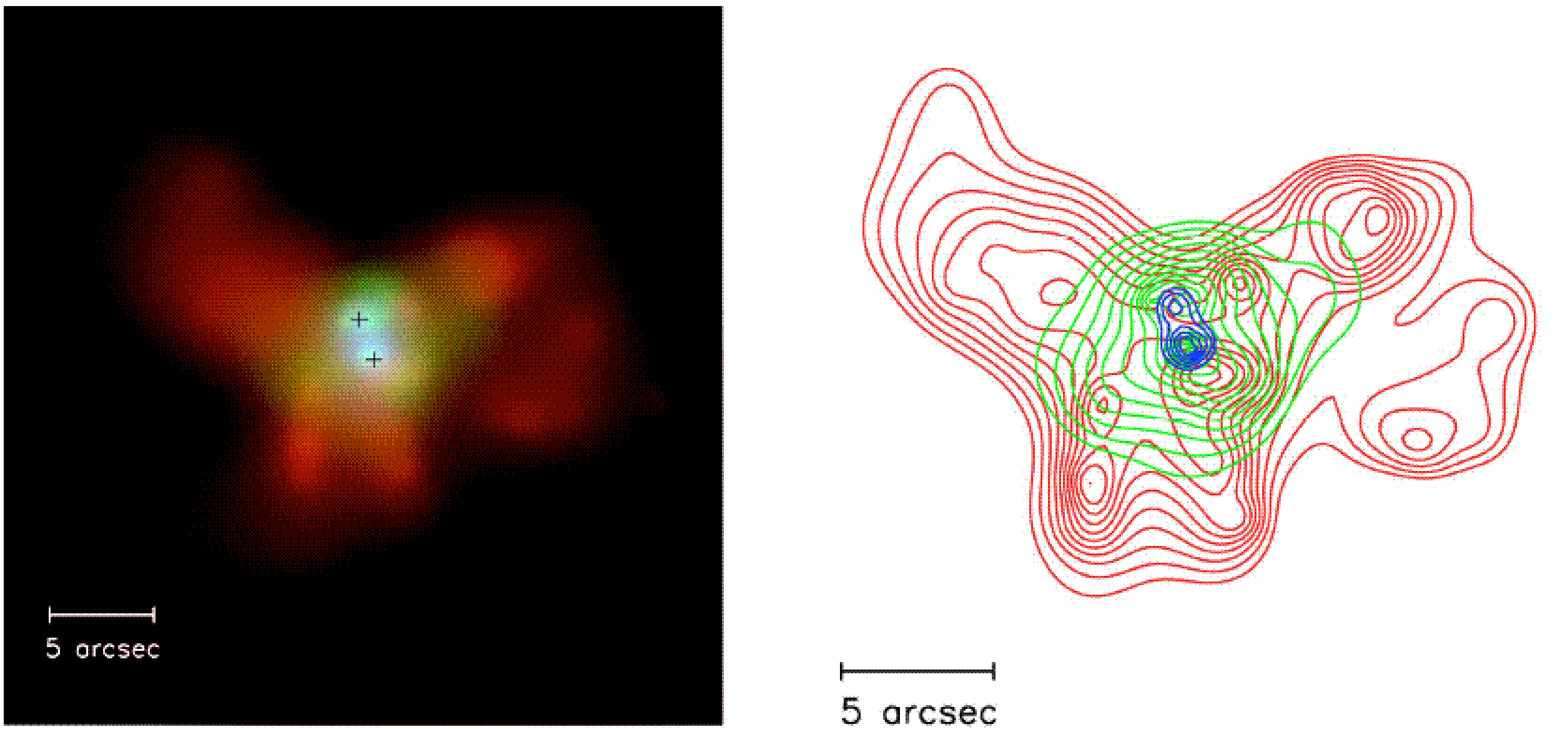
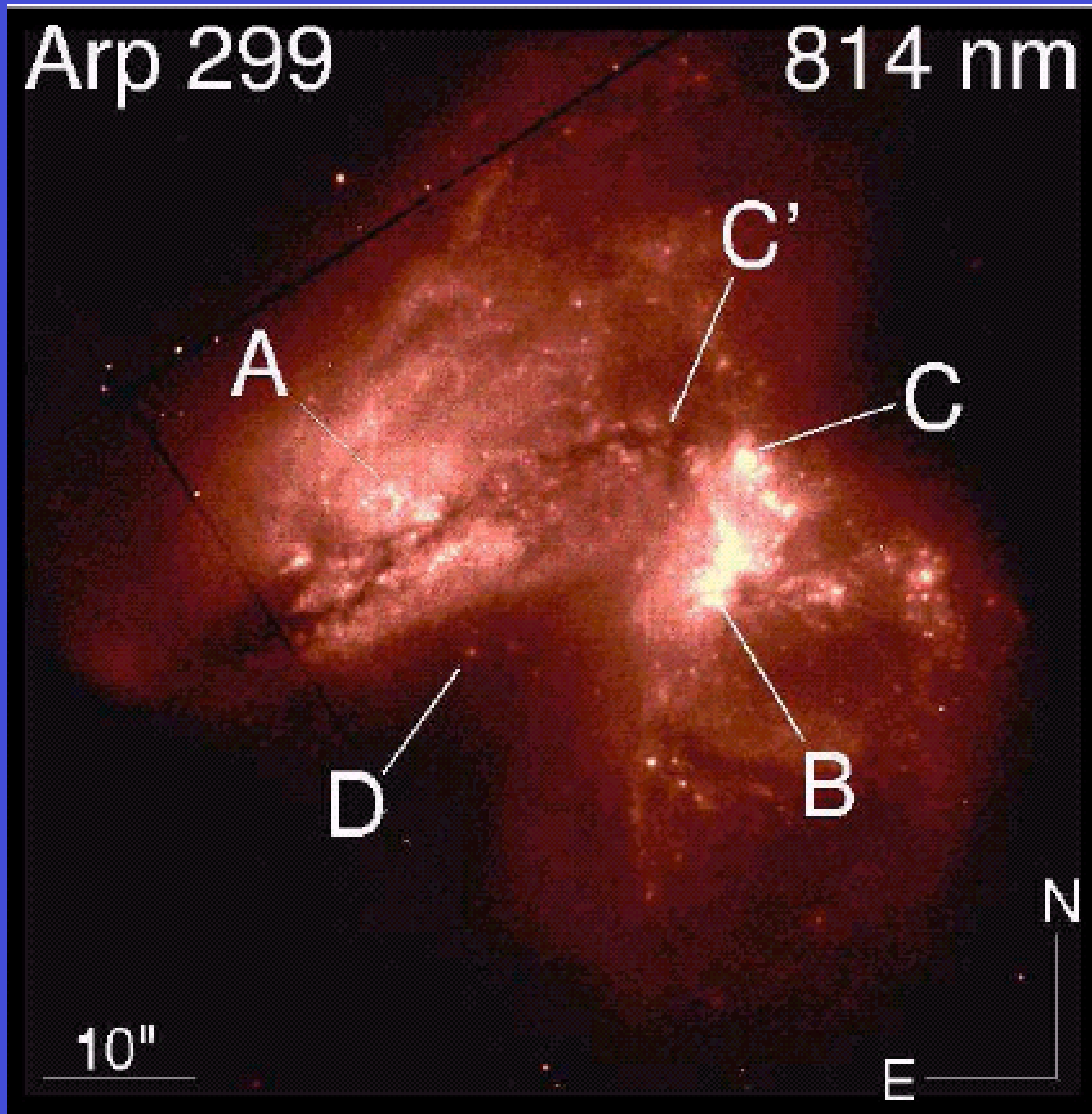
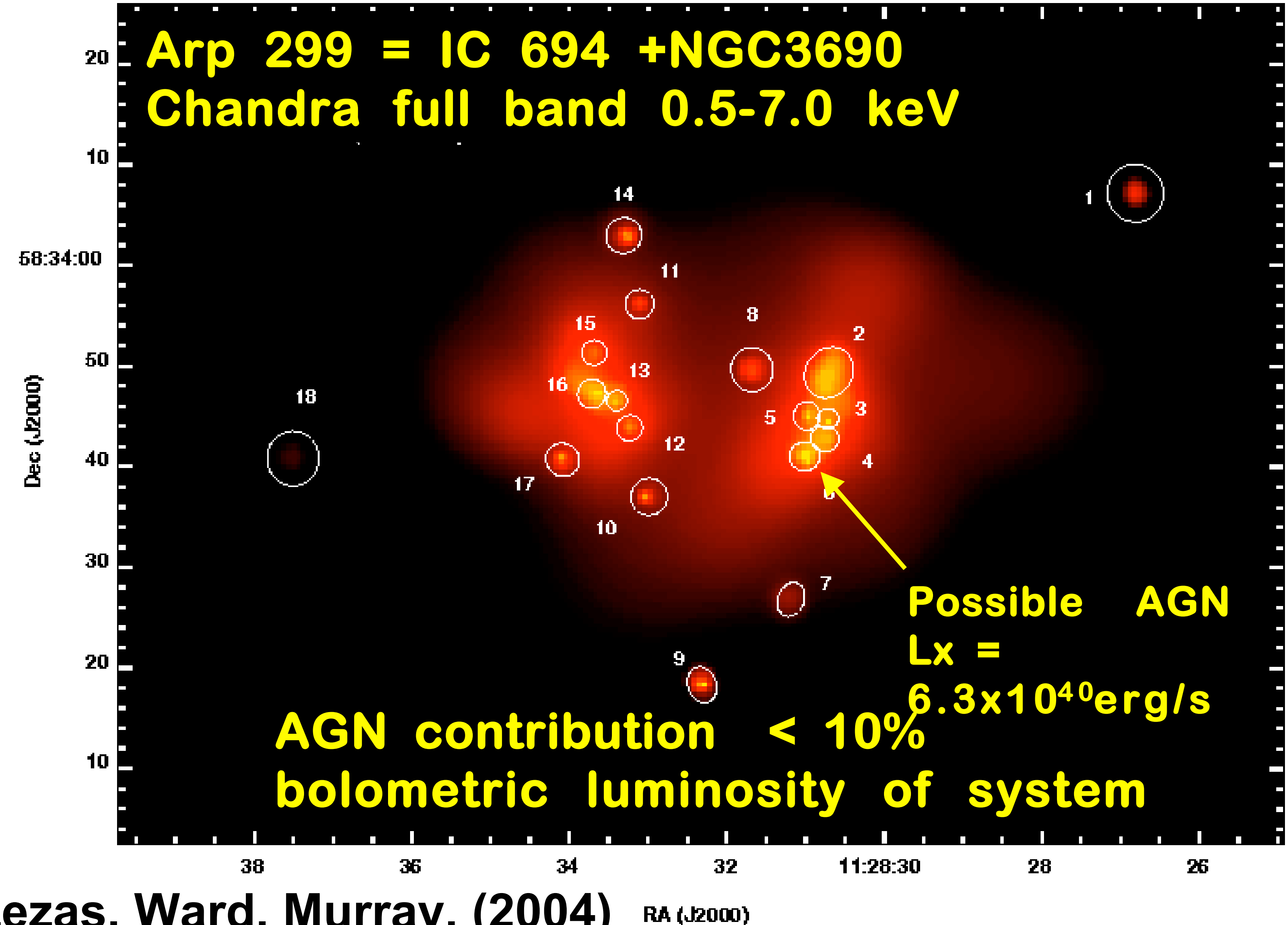


FIG. 3.—Multicolor image of NGC 6240. Red = soft (0.5–1.5 keV), green = medium (1.5–5 keV), and blue = hard (5–8 keV) X-ray band. The right image shows contour plots using the same color coding.


Arp 299
814 nm
C'
A
C
B
D
N
E
10"

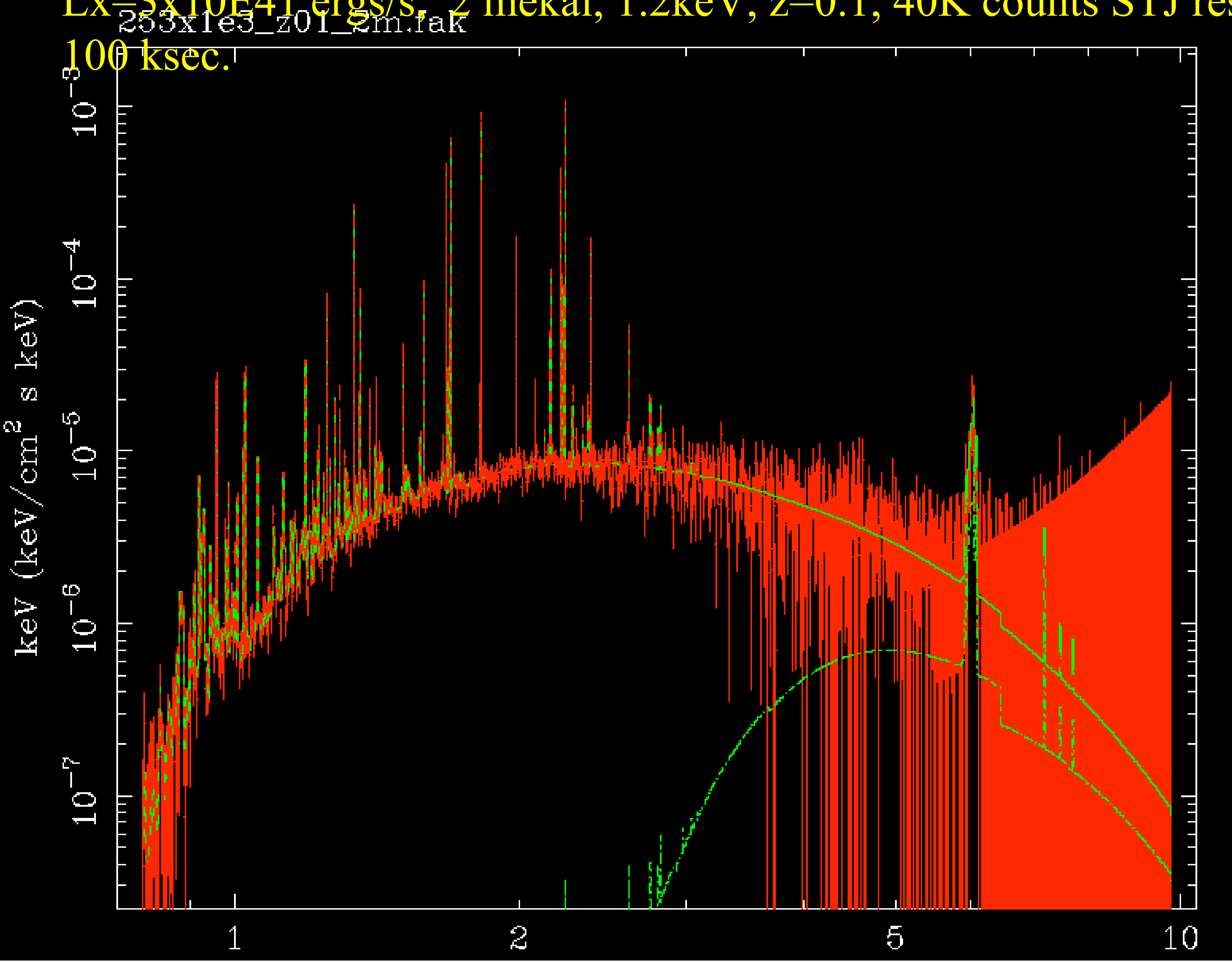


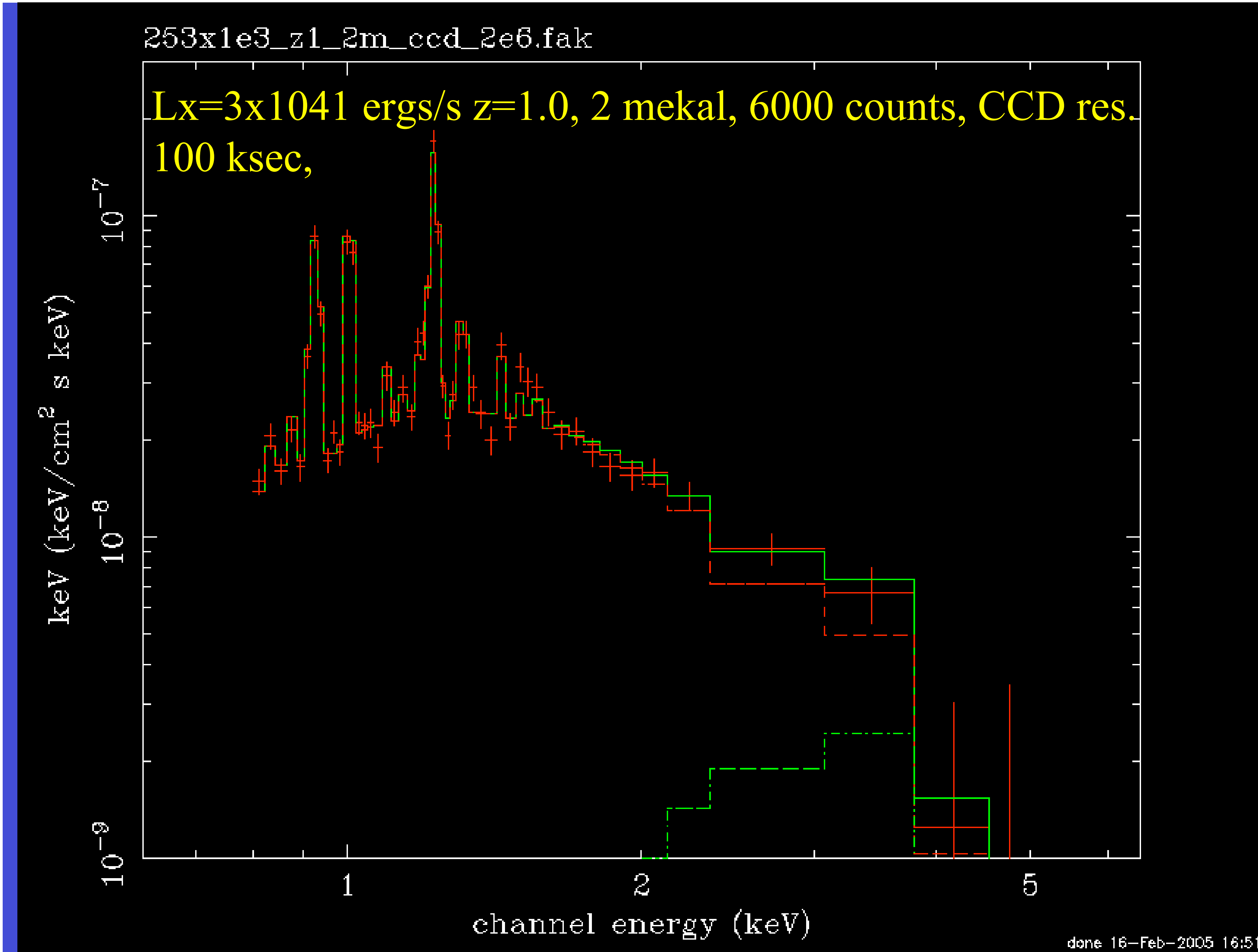
Zezas, Ward, Murray, (2004)

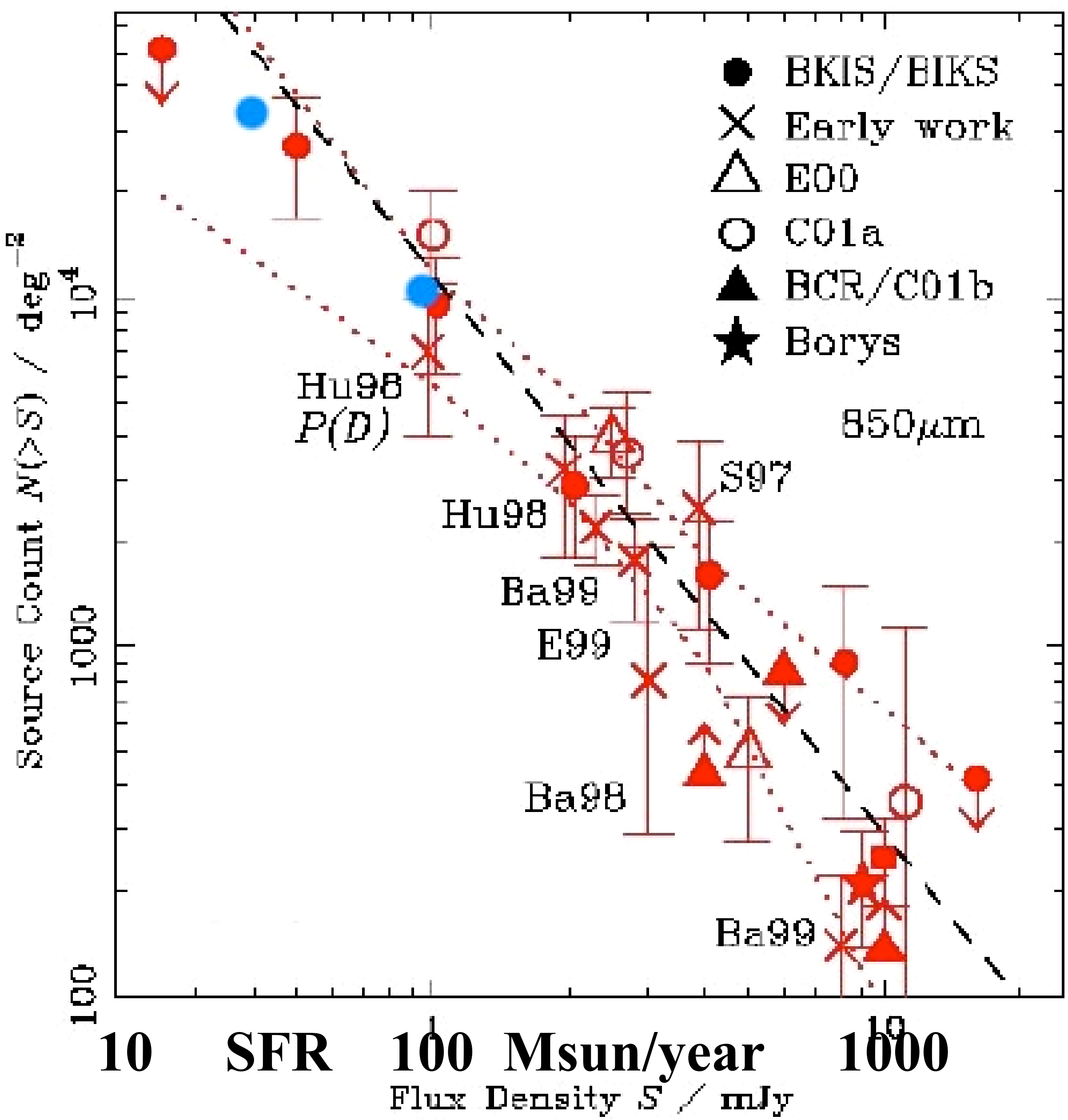
18 point sources Lx > 10^{39} erg/s

– A full band (0.5-7.0 keV) adaptively smoothed image of Arp 299 together with the discrete sources follow
he source regions correspond to the appertures used the estimate their intensities and extract their spectra.

Lx=3x10E41 ergs/s, 2 mekal, 1.2keV, z=0.1, 40K counts STJ res 100 ksec.

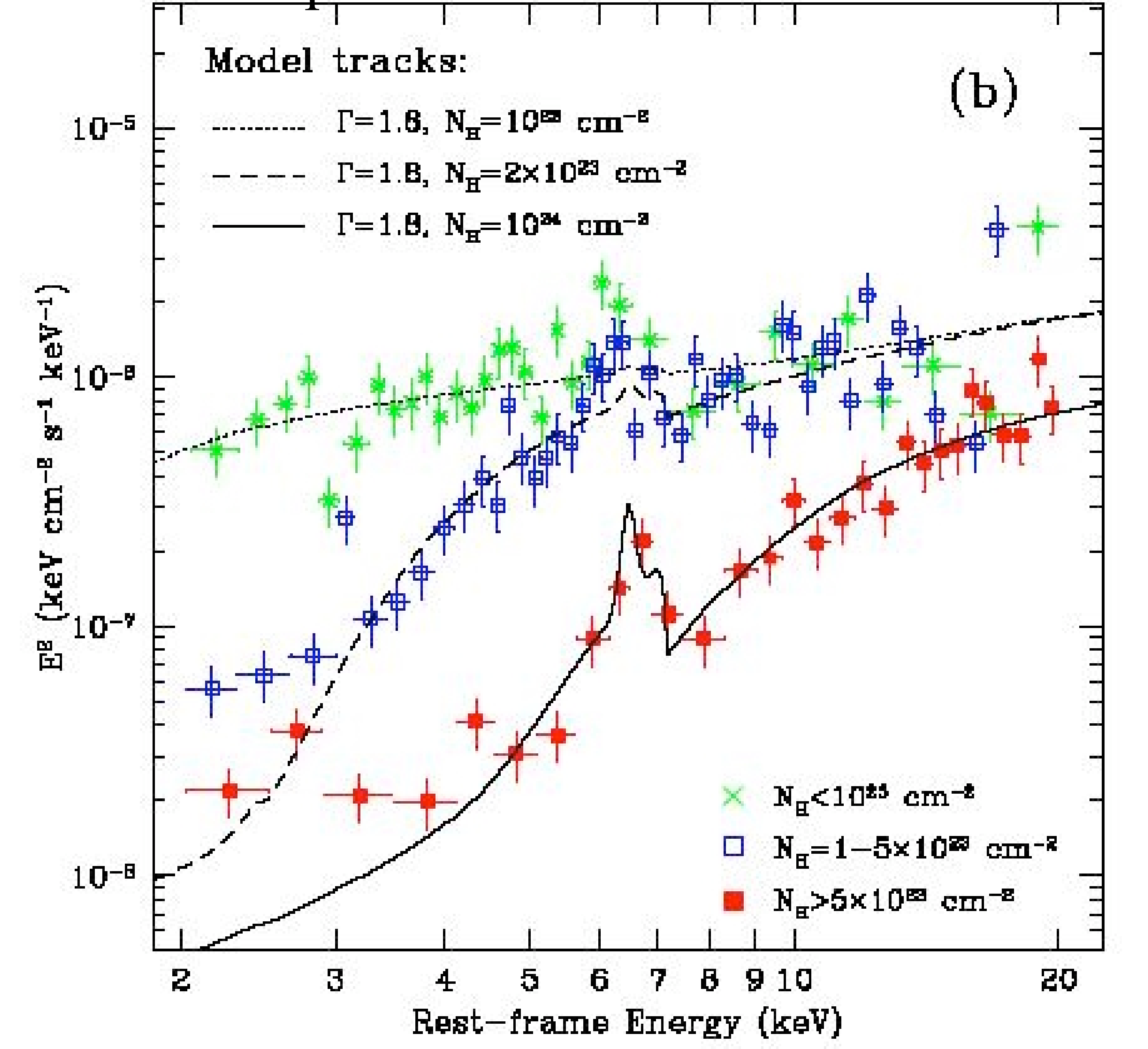



253x1e3_z1_2m_ccd_2e6.fak
Lx=3x1041 ergs/s z=1.0, 2 mekal, 6000 counts, CCD res.
100 ksec,
keV (keV/cm^2 s keV)
10^{-7}
10^{-8}
10^{-9}
1
2
5
channel energy (keV)
done 16-Feb-2005 16:51

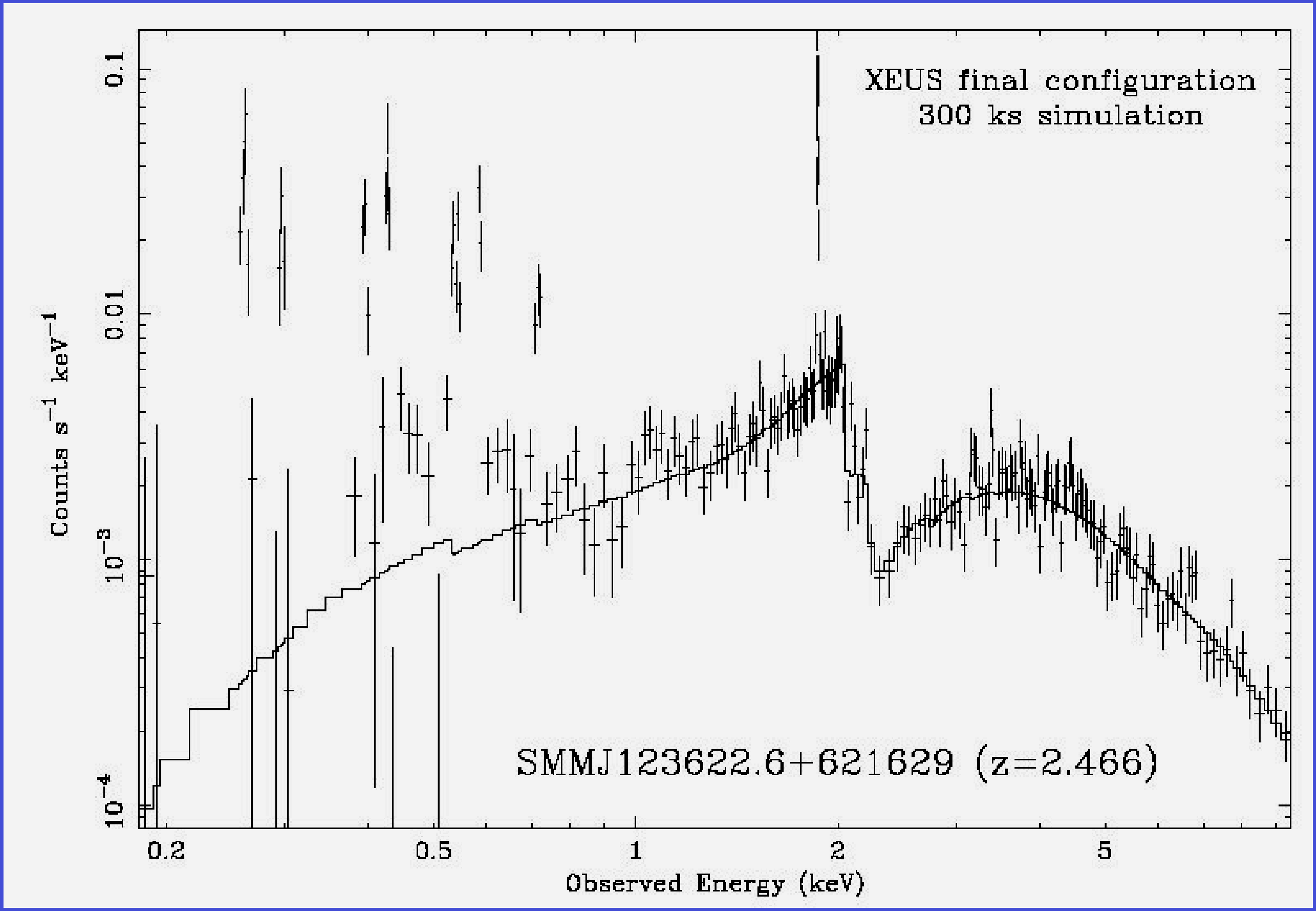


BKIS/BIKS
Early work
E00
C01a
BCR/C01b
Borys
850μm
Hu98
P(D)
Hu98
Ba99
E99
Ba98
S97
Ba99
Source Count N(>S) / deg^{-2}
100
1000
10^4
10
SFR
100
Msun/year
1000
Flux Density S / mJy

Chandra Deep Field North 2 Msec.SMGs 16 detections

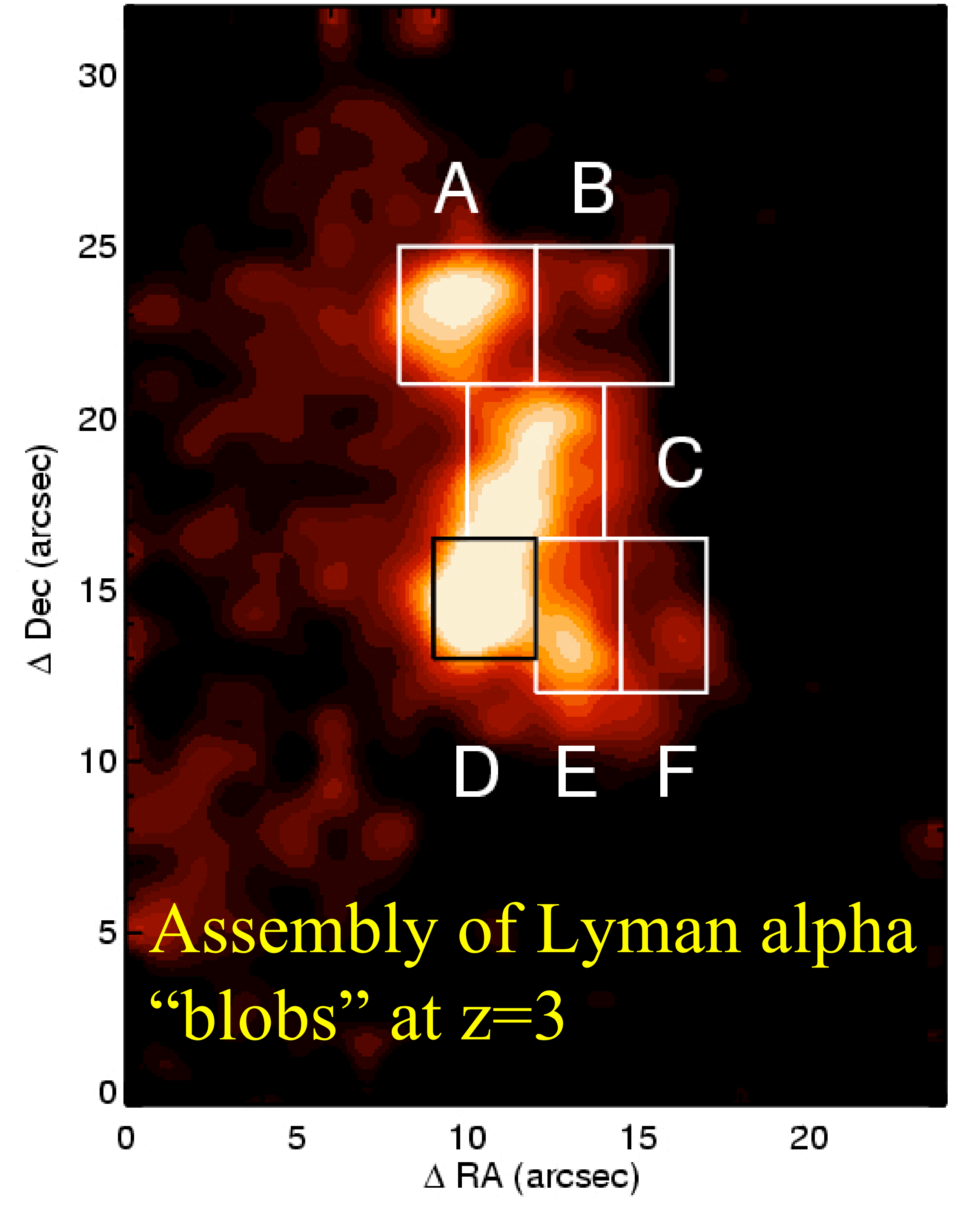


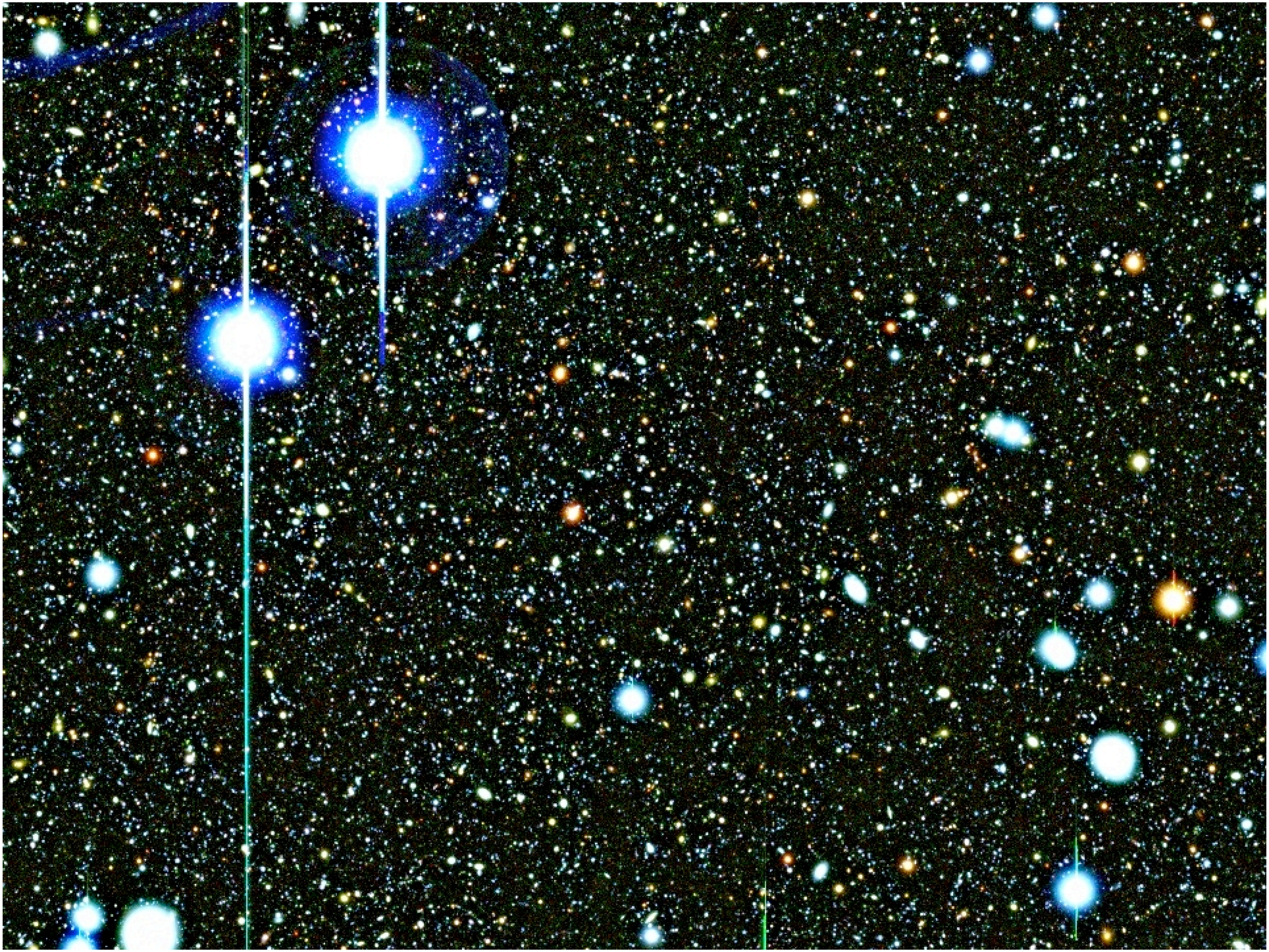
AGN wind or starburst wind?

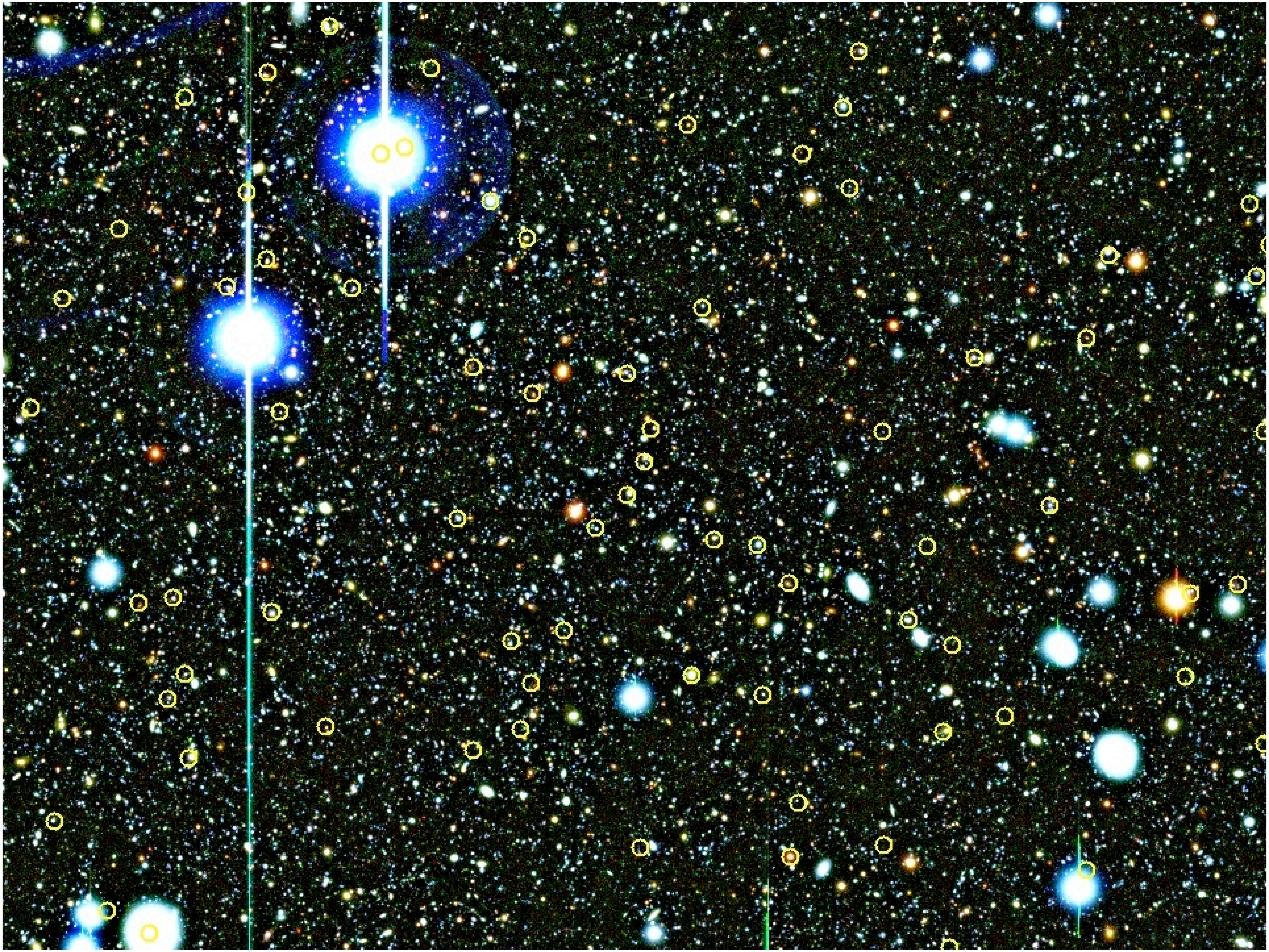


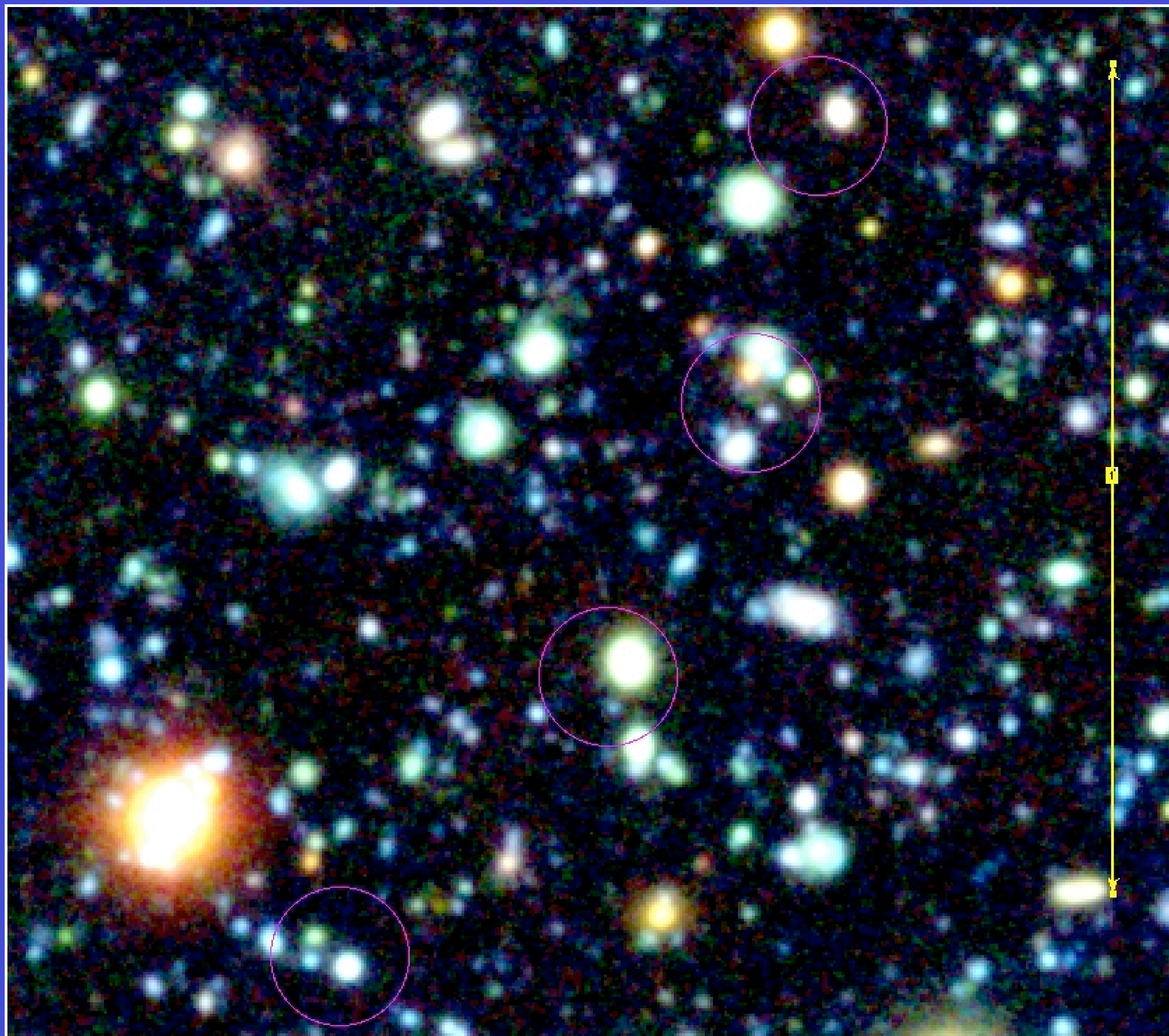
Requirement of Spatial Resolution

- For sources embedded in diffuse emission
- For complex sources with multiple spatially distinct emitting regions (cf. NGC4945), and for merging systems
- For source ID, and follow-up at other wavelengths

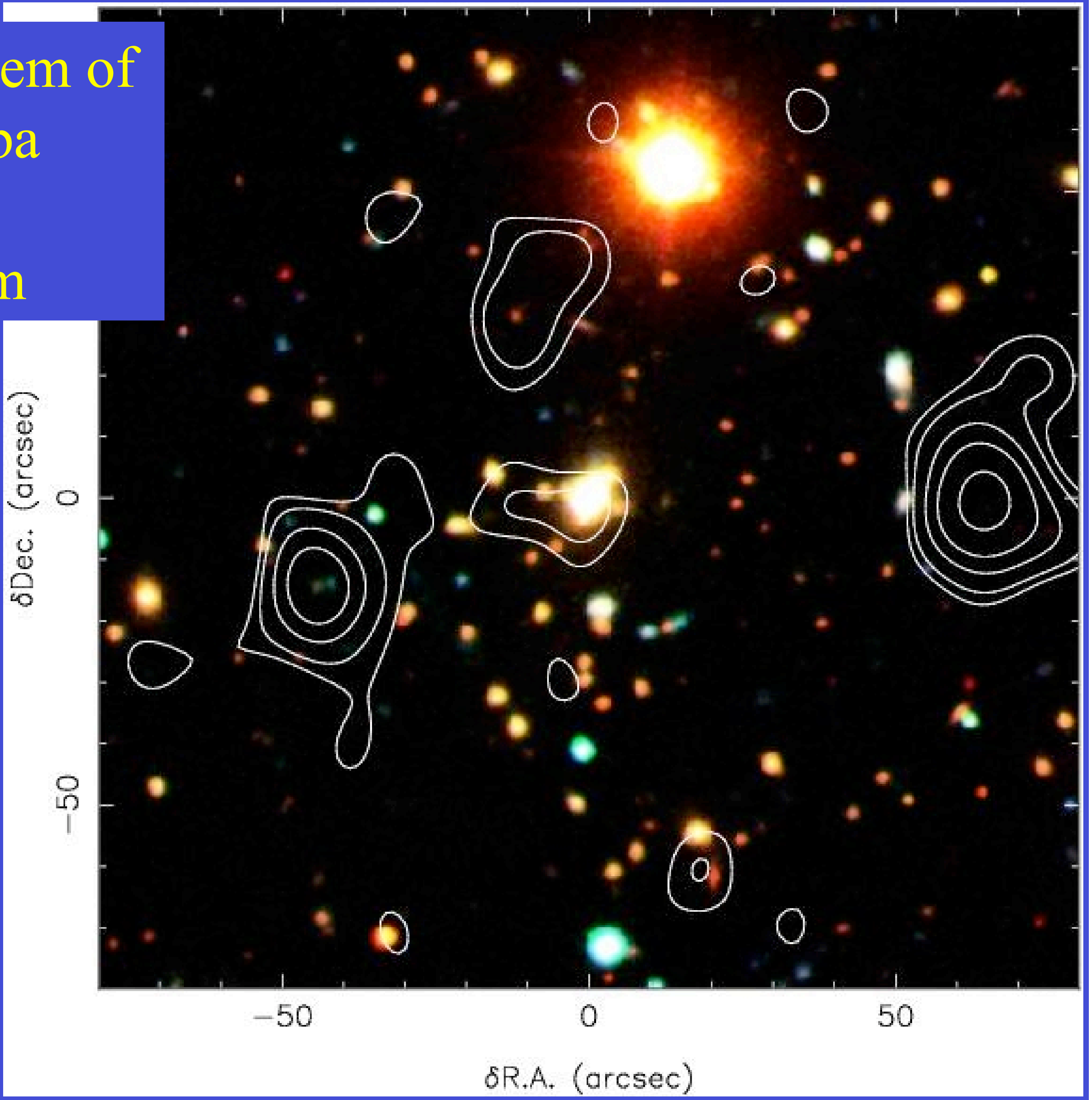

A
B
C
D
E
F
Assembly of Lyman alpha "blobs" at z=3
Δ Dec (arcsec)
Δ RA (arcsec)
0
5
10
15
20
25
30





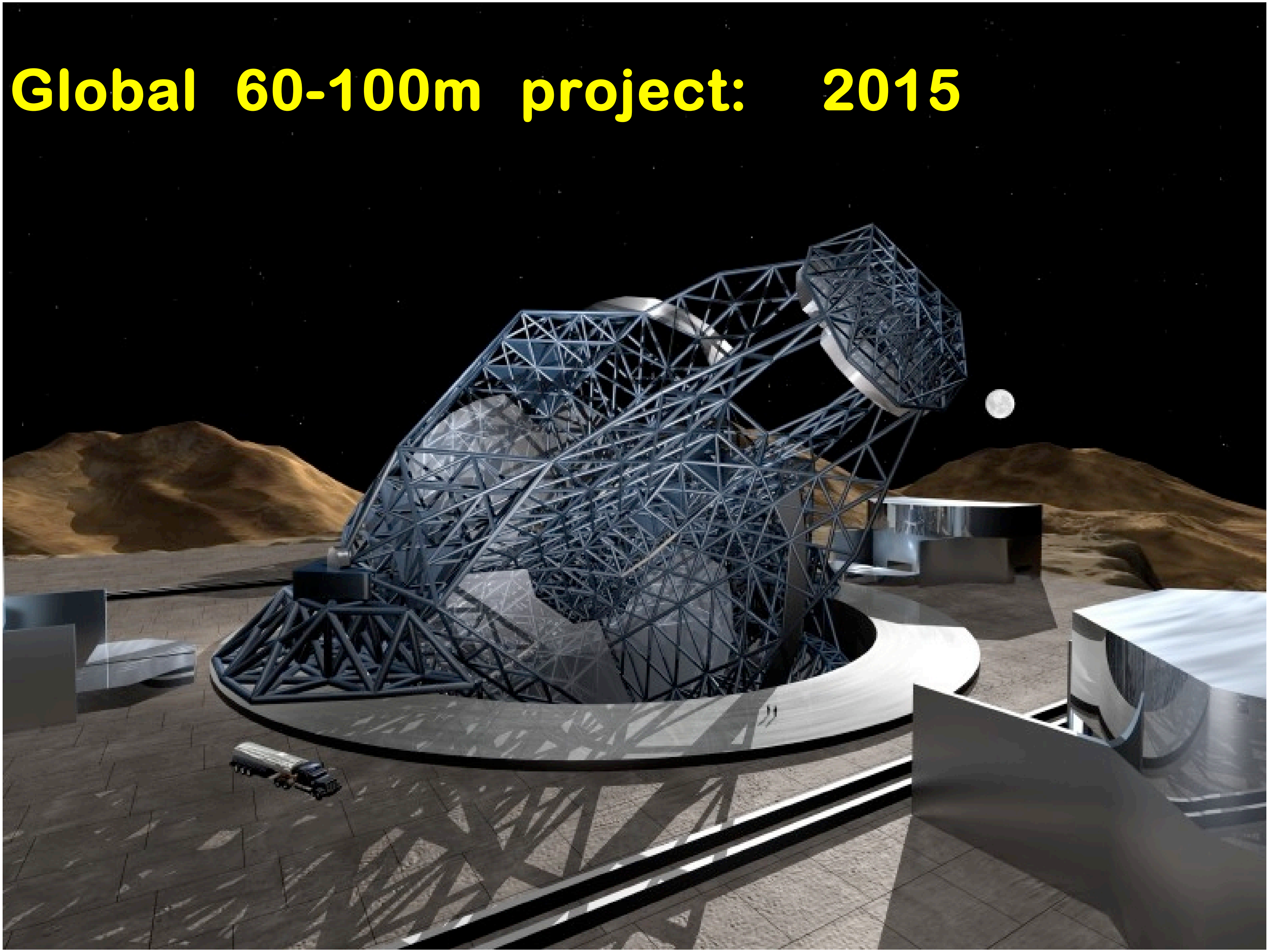


Recall the problem of identifying Scuba sources using a 15 arcsec beam

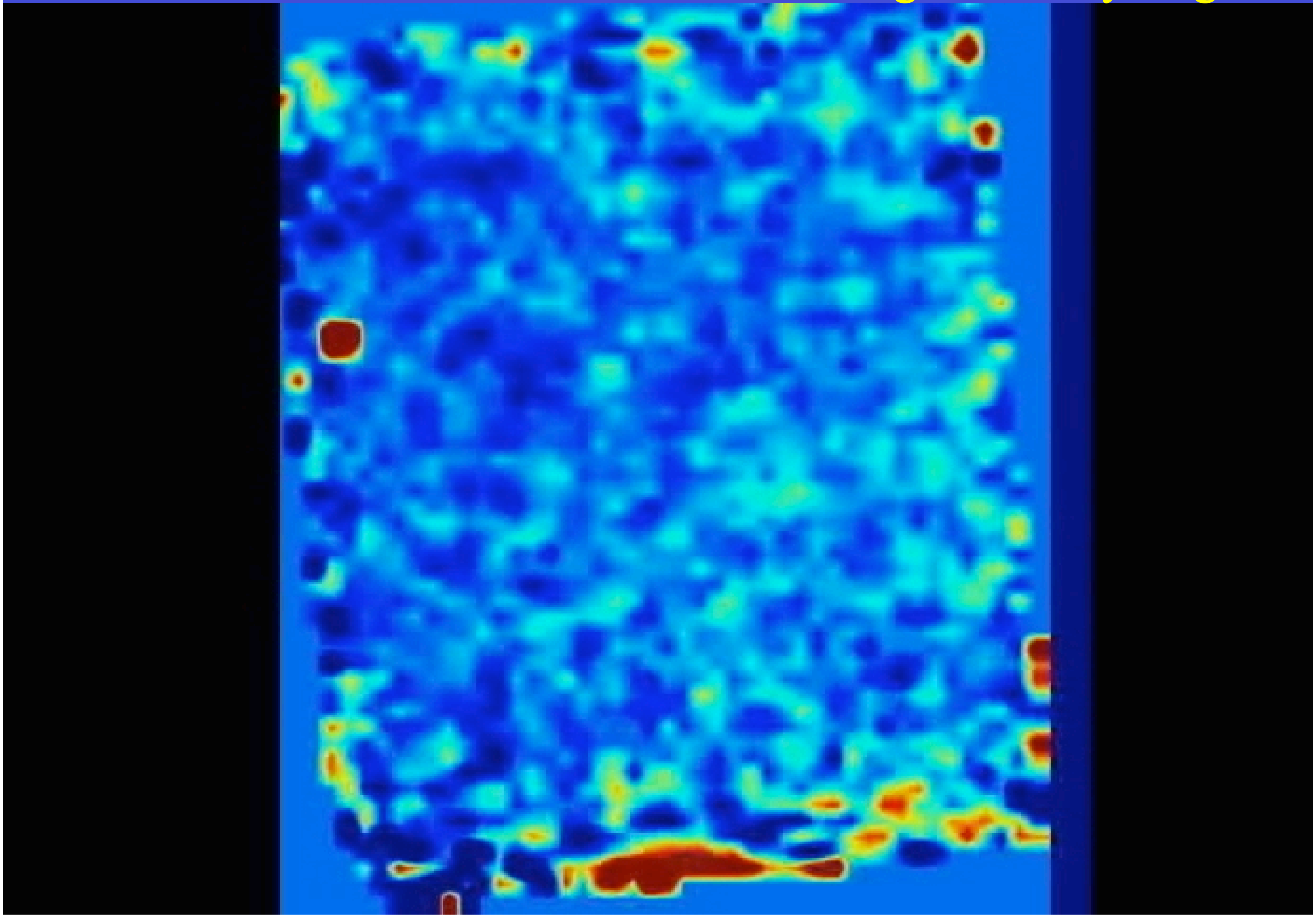


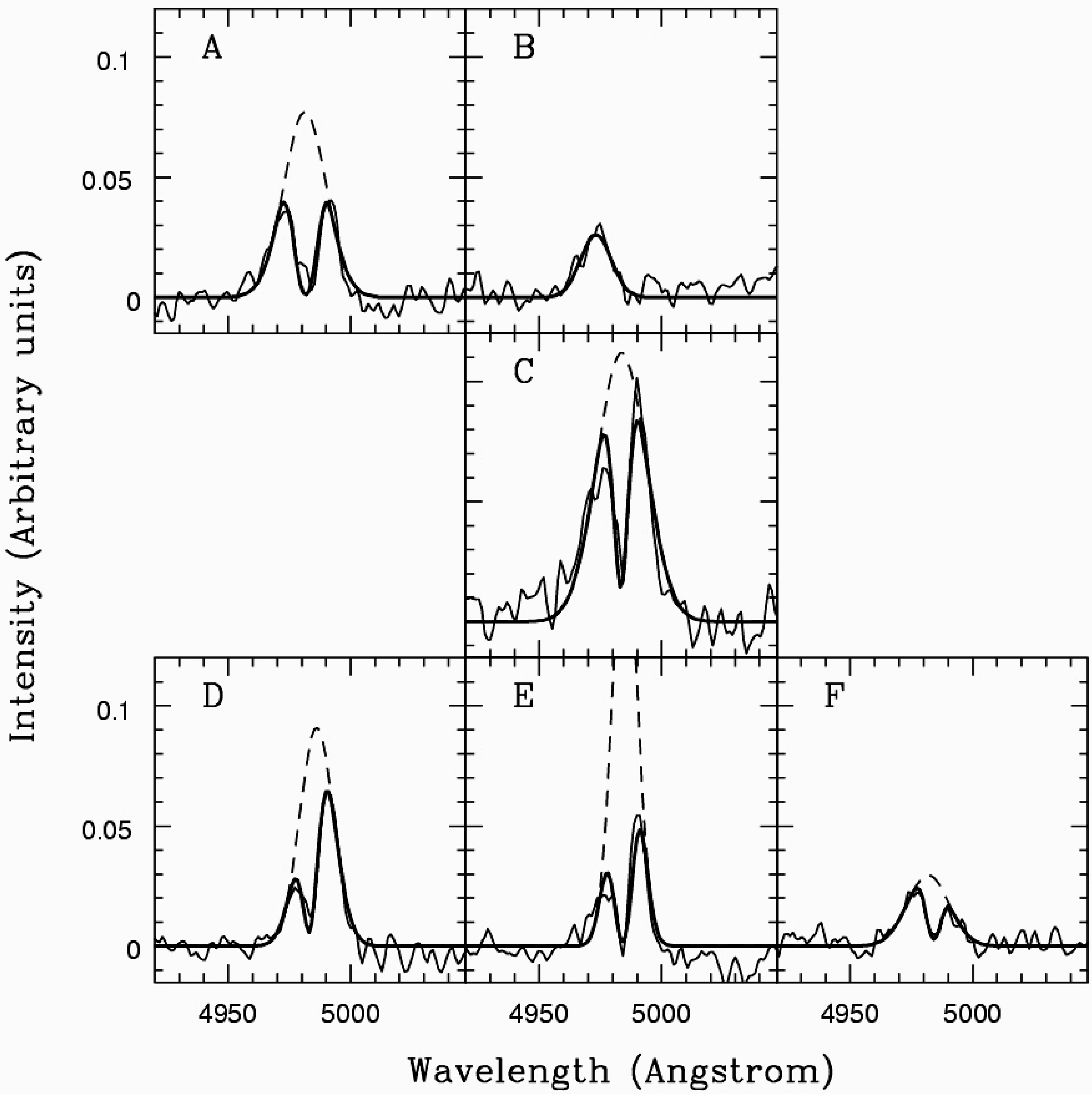
And finally….

unique is good
but complementarity is good too

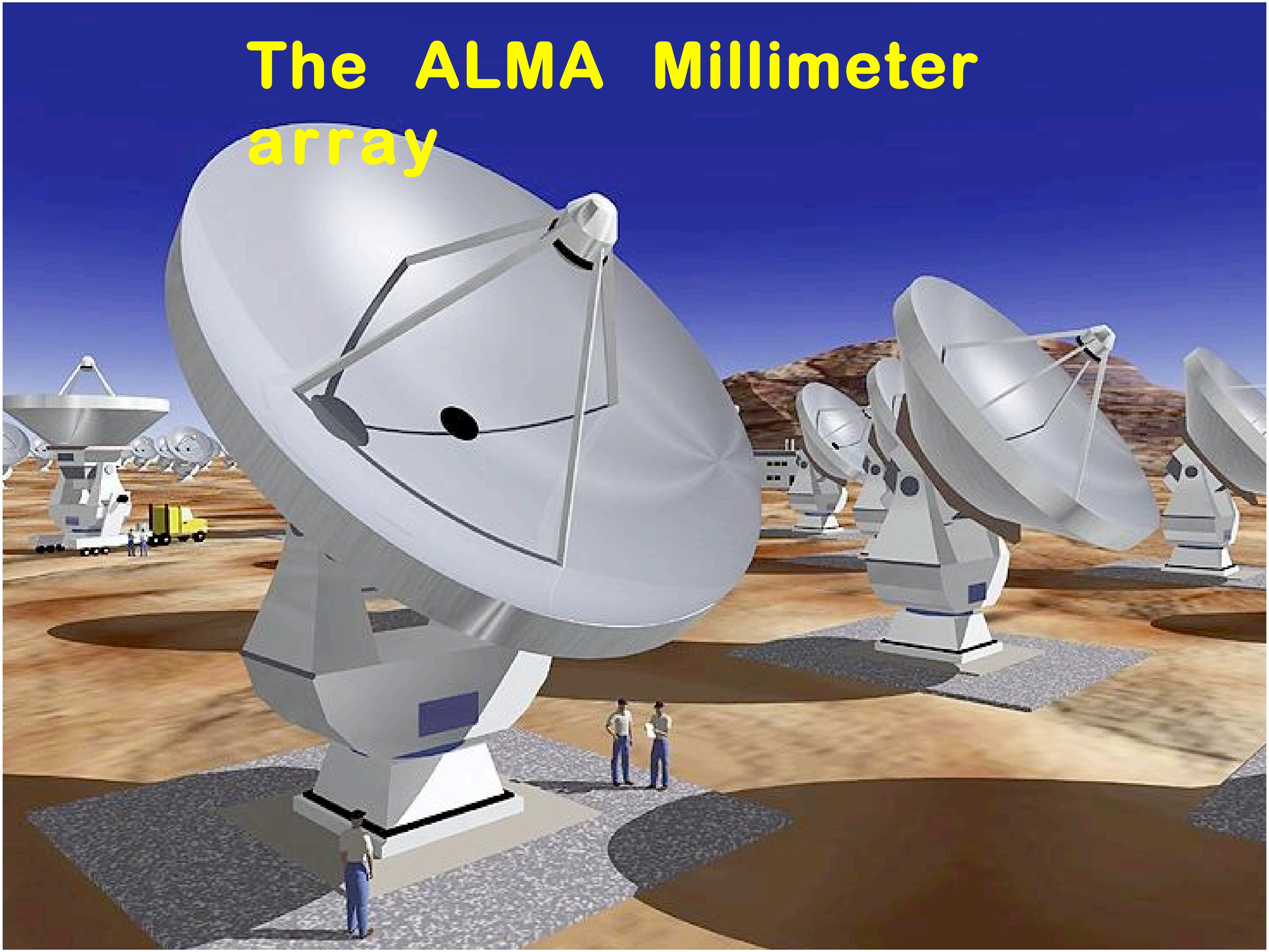

Global 60-100m project: 2015

Use facilities at other wavebands to find good X-ray targets




A
B
C
D
E
F
0.1
0.05
0
4950
5000
Intensity (Arbitrary units)
Wavelength (Angstrom)

The ALMA Millimeter array



The Square Kilometre Radio Array

Major Future Facilities

- ALMA (2010): will resolve sub-mm structures on 100pc scales at medium redshift
- JWST (2012?): will define stellar populations at high redshift
- ELT 30-100m? (2015?): will provide excellent spatial resolution and velocity maps
- SKA (2018?): HI environment (cf. M82, NGC253), will calibrate the SFR vs radio relation – mix of thermal and non-thermal radio components, with implications for binary contribution via knowledge of the starburst age